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SPECIAL REPORT

To

Technology Utilization Office
Code KT
National Aeronautics and Space Administration

Review of Federal Research and Development in Pavement Striping Materials

30 July, 1971

PREPARED BY:

Technology Applications Group

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INTRODUCTION

The BSCP Technology Application Group (TAG) has actively participated in the design and early developmental phases of the ICMA-NASA Technology Application Program. Following the priortization of the initial set of city-generated problems, NASA's Office of Technology Utilization assigned to TAG the task of determining for selected problems the extent of relevant federal R&D support.

The basic reasons for this task were to: 1) identify federal or federally sponsored 'centers of excellence' which might help in problem definition and in focus on appropriate technology; 2) avoid duplication of R&D effort; and 3) identify R&D performers where new technology could best be injected for consideration.

The first ICMA problem on which TAG focused was "Pavement Striping." Appendix A contains both the ICMA and Stanford Research Institute TATeam Problem Statements for this problem. Basically, the areas for improvement are:

1) decrease in drying time
2) increase in wet weather visibility
3) increase in durability (normal wear as well as snowplow damage)
4) increase in adherance to pavement
5) increase cost-effectiveness of striping systems

The SRI Problem Statement includes a good summary of currently used striping materials. Also included in Appendix A is a 1969 article by Bernard Chaiken in Public Roads which summarizes R&D of traffic marking materials.

The TAG methodology for this investigation consisted of: 1) reviewing information currently available and conducting information searches to identify relevant funders and performers of relevant R&D; 2) contacting identified federal agency representatives to fully identify pertinent R&D effort; 3) meeting with federal agency personnel and industrial personnel to determine characteristics of current and planned advances in technology state-of-art; and 4) reviewing pertinent publications.

This report summarizes the information gathered to date of federal R&D efforts directly relevant to traffic marking materials. Recommendations for further NASA and ICMA actions are also presented.

Federal Pavement Marking R&D Sources

Department of Transportation

Within DOT, much highway related research is carried out within or under the sponsorship of the Federal Highway Administration (FHWA), the National Highway Safety Bureau (NHSB), The Highway Planning and Research (HP&R) activity, and the funding of the National Cooperative Highway Research Program (NCHRP). HPR activities are supported jointly by the Federal Government and individual states. NCHRP effort is jointly funded by the FHWA, the American Association of State Highway Officials (AASHO) and the National Academy of Sciences Highway Research Board (HRB).

Some research relevant to pavement markings is also carried out by the Federal Aviation Administration (FAA). Research performed by the FAA, and by the Department of Defense (DOD) for FAA, is in the area of runway marking materials and is relevant to pavement marking materials research.

FHWA Staff Research Studies. During FY-'69 and FY-'70, the FHWA did no in-house research directly related to pavement marking materials. Research related to pavement thickness determination (FHWA Code 2723023) and to rest area waste requirements (FHWA Code 2830642) were continued. The SRI TATeam is knowledgeable of these efforts.

FHWA Contract Studies. During FY-'70, the Battelle Memorial Institute carried out Phase I ($36,000) of a project entitled "Development of a New Low-Profile Highway Striping for Nite-Wet Visibility. Phase I- Practical Feasibility (FHWA Code 3644303, Contract No. FH--11-7445). BSCP-TAG has contacted Battelle to obtain initial information on this project. BMI is using plastic ray corner retroflectors, 1/8 "thick, smooth top surface, which is glued onto, or into a groove in the road. Focus is on wet-nite visibility in snow-plow states.

Within the FHWA, Bernard Chaiken of the Office of Research and Development is responsible for R&D coordination in pavement. He is also considered 'the' expert on pavement marking materials within FHWA. The pavement striping R&D FY-'73 program will be an active one which will be an active one which will rely on Federal/State matching dollars. Between fifteen and twenby studies, carried out by the states and coordinated with the NCHRP, will probably be underway. Bob Connor of the Office of Traffic Operations noted that seventeen states are currently carrying out R&D, with federal money, on the evaluation of beaded striping. A report is due late in 1971 and should be of interest to the cities. Contact reports relevant to FHWA interfaces are in Appendix B.

The FY-1969 "Highway Research and Development Studies" lists the following 16 studies relating to pavement striping as "in progress."

Program Area Code	Sponsor and Conducting Agency	Title	Current Year Cost
4511003	Pennsylvania, Singer	"A System For Measuring & Marking No-Passing Zone Limits"	$ 44,000
4532724	Louisiana, Louisiana Polytechnic	"Highway Lane Marking With Reflective Materials"	$ 2,000
5532021	NCHRP, Penn State	"Roadway Delineation Systems"	$209,000
4644053	California, State	"Development & Evaluation of Reflective Traffic Lane Markers"	$ 12,000
4644284	California, State	"Grooved Traffic Strips"	$ 1,000
4644173	Colorado, State	"Reflective Traffic Bead Study"	$ 6,000
4644183	Georgia, Georgia Institute of Technology	"Wet Night Visibility"	$ 27,000
4644194	Kansas, State	"Paint Stripe & Glass Bead Study"	$ 8,000
4644095	Kentucky, State	"Plastic Striping Performance Surveys"	$ 3,000
4644104	Kentucky, State	"Durability of Traffic Paint on Portland Cement Concrete Pavements"	$ 2,000
4644314	Louisiana, State	"Evaluation of Raised Pavement Markers"	$ 18,000
4644262	Missouri, State	"Investigate Paints and Glass Beads Used In Traffic Delineation"	$ 35,000
4644294	New Jersey, State	"Study of Glass Beads With Flotation Properties"	$ 8,000
4644135	New York, State	"Plastic Marking Materials for Pavements"	$ 27,000

Program Area Code	Sponsor and Conducting Agency	Title	Current Year Cost
4644144	North Dakota, N.D. State Univ.	"Improved Highway Marking Paints"	$ 3,000
4810003	Washington, D.C., State	"Pavement Marking Materials Performance"	$ 2,000

As is apparent, most of the federally sponsored R&D in this area during FY-'69 was done by the States.

NHSB Administrative Contract Studies. There were no R&D efforts related to pavement markings carried out under NHSB sponsorship during FY-'70.

HP&R Studies. During FY-'70, HP&R R&D efforts conducted by the States relevant to pavement markings were:

Program Area Code	Sponsor and Conducting Agency	Title	Current Year Cost
4644034	Alabama State Highway Department	"Traffic Marking Beads"	$ 5,000
4644274	California State Highway Department	"Development & Evaluation of Reflective Traffic Lane Markers"	$ 12,000
4644284	California State Highway Department	"Grooved Traffic Stripes"	$ 4,000
4644362	Connecticut State Highway Department	"Evaluation of Hot Applied and Fast Dry Paints on high ADT Roads"	$ 16,000
4644044	Indiana State Highway Department	"Traffic Marking Materials Experiment"	$ 3,000
4644194	Kansas State Highway Department	"Paint Stripe & Glass Bead Study"	$ 8,000
4644095	Kentucky State Highway Department	"Plastic Striping Performance Surveys"	N/A
4532124	Louisiana, Louisiana Polytechnic	"Highway Lane Marking With Reflective Materials"	N/A
4644314	Louisiana State Highway Department	"Evaluation of Raised Pavement Markers"	$ 14,000

F.ogram Area Code	Sponsor and Conducting Agency	Title	Current Year Cost
4644323	Maryland State Highway Department	"Development of a Laboratory Method of Predicting Wear Resistance of Aggregates"	$ 32,000
4644024	Mississippi State Highway Department	"An Evaluation of Road Marking Materials"	$ 7,000
4644262	Missouri State Highway Department	"Investigation of Paints and Glass Beads Used in Traffic Delineation Markings"	$ 37,000
4644294	New Jersey State Highway Department	"Evaluation of Floating Glass Beads for Traffic Stripes"	$ 4,000
4644135	New York State Highway Department	"Pavement Marking Materials"	$ 36,000
4644144	N. Dakota State University	"Improved Highway Marking Paints"	$ 4,000

As previously noted, most of the relevant pavement marking R&D sponsored by FHWA is carried out by the States. The HP&R activity is jointly funded, 90/10 on interstate and 50/50 on non-interstate, federal-to-state-dollars.

NCHRP The Highway Research Board (HRB), soon to become the Transportation Research Board, is a unit of the Division of Engineering of the National Research Council. The HRB operates under the corporate authority of the National Academy of Sciences. One of the HRB's four divisions is the National Cooperative Highway Research Program (NCHRP). NCHRP is funded by the American Association of State Highway Officials, is administered by the HRB, and works in cooperation with the FHWA. States contribute 4 1/2% of their 1 1/2% share of FHWA HP&R funds to the NCHRP. Total NCHRP resources are about $3 1/2 million per year and their trend is to fund projects in the $100,000 to $300,000 bracket. Contact Reports are in Appendix C.

Mr. Bill Williams, NCHRP project engineer, has been responsible as contract monitor for pavement striping R&D since 1964. Included in Appendix C are copies of three RFPs covering NCHRP R&D in pavement striping. NCHRP Report #45 is included as Appendix D and is the result of Contract 5 with Southwest Research Institute. NCHRP Report #85, for Contract 5 continued, has not been obtained. Contract 5-5A, soon to be let to a university, will provide $200,000 for wet-nite visibility in snow plow areas markings R&D. This effort is parallel to the Battelle effort. NCHRP studies to date are as follows:

Program Area Code	Sponsor and Conducting Agency	Title	Cost
5532021	NCHRP, Penn State	"Roadway Delineation Systems," year 2 of 3 yrs.	$209,000 (FY-'69) $104,000 (FY-'70)
5532012 (5-5, 5-5 cont'd)	NCHRP, Southwest Research Institute	"Nightime Use of Highway Pavement Delineation Materials, Phase I,II"	1967-1969 Total Cost of $100,000
(5-5A)	(Pending ?)	"Development of Optimum Specifications for Glass Beads in Pavement Markings"	

The NCHRP administers two information storage and retrieval systems, the Highway Research Information System - HRIS (contact Art Mobley) and the Transportation Research Activities Information Systems - TRAIS (contact Mr. Schafer). Both systems can be searched for reasonable fees. It is recommended that ICMA-TAP develop close interface with these two systems as a means of keeping up-to-date on current R&D related to city transportation problems.

A number of pavement striping R&D reports have been procurred by BSCP-TAG in microfiche form. These will be reproduced and hard copy provided to ICMA as soon as possible.

FAA The Federal Aviation Administration conducts both in-house and external R&D on materials for airport runway markings. In-house R&D is generally conducted at the National Aviation Facilities Experimental Center (NAFEC). Fred Horne of FAA's R&D office indicated that reports of in-house R&D are available from NTIS. Appendix E contains Contact Reports and FAA references to pertinent literature. Several reports have been obtained. Most of NAFEC work is on the visibility evaluation of various marking and lighting systems.

External R&D for the FAA has been done by the Institute of Transportation and Traffic Engineering (ITTE) of the University of California at Berkeley and by various groups within the Department of Defense. Human factors analyses have been done by ITTE and by Human Sciences Research, Inc. of Arlington, Virginia. Since most of the materials related R&D has been done for the FAA by DOD, DOD efforts are discussed next.

Department of Defense

Within DOD, pavement marking materials R&D has been conducted by:

1. Materials Research Support Division
   U.S. Army Mobility Equipment Research & Development Center
   Fort Belvoir, Virginia

2. DOW Chemical Co. under contract to (1) above
3. Directorate of Civil Engineering (Code AFPRE)
   Bolling Air Force Base
   Washington, D.C.
   U.S. Air Force
4. U.S. Naval Civil Engineering Laboratory
   U.S. Navy
   Port Hueneme, California
5. Chemical Research and Development Labs.
   Army Chemical Center
   Edgewood, Maryland
   U.S. Army

Contact Reports and literature references for these agencies are included in Appendix F. Copies of several DOD reports have been obtained.

The materials R&D underway at Bolling AFB and at Fort Belvoir is being done in conjunction with the FAA. Both Emil York (Army) and William Helm (Air Force) coordinate their R&D with Fred Horne of the FAA. Their R&D is aimed at better runway striping paints with a requirement for a 1.9 retroflectivity due to a angle of divergence greater than that for autos. Belvoir is evaluating DOW and Shell epoxy paints and glass beads are also used. Skid resistance, blistering of subcoats, drying times, and cracking are some of the problems encountered. These efforts are in the development stage at this time. The key contact man is Fred Horne.

The Navy R&D (Port Hueneme) was not done in conjunction with Army or Air Force R&D. Port Hueneme no longer has an active program in this area, but they conducted extensive tests of existing highway and airfield paints based on TT-P-85, TT-P-110 and TT-P-115 paint specifications. Extensive tests of other formulations (NCEL Formulations 108, 109, 110, 101, 115 and 114) were also carried out. The future of Navy R&D in this area is uncertain, but their evaluation efforts are impressive. BSCP-TAG has copies of relevant reports from Port Hueneme. They key contact is R.W. Drisko.

The R&D of the Army Chemical Center concerning the silver plating of glass beads has not yet been investigated.

DOW Chemical Company's Washington Office was contacted and they promised to forward relevant technical information. This data has not yet been received.

<u>Industry Organizations</u>

Although assessing the current commercial state-of-art was not part of this effort, BSCP-TAG participated, at the invitation of ICMA-TAP, in a meeting with Mr. Paul Yard, Manager of 3M's Pavement Marking Systems Division. Mr. Yard provided us with a detailed review of his Division's history, technical capability, traffic marking materials product line, and R&D in marking materials. In his discussion of future marking products and systems, he disclosed to us that 3M will soon be offering a 'guaranteed marking' service and a 'contract striping' service. These services are intended to provide pavement marking capabilities which exceed current striping technology. While this information cannot be disclosed at this time, the 3M services involve the rapid application of custom premixed materials including standard and bisymmetric glass beads with a two-year guarantee at a very reasonable price. The equipment to provide these capabilities has developed by 3M and is very sophisticated. 3M is conducting in-house R&D on snowplow-resistant markers and other new marker products for which they have filed for patent protection. None of the 3M R&D is federally funded.

It appears that the soon-to-be announced 3M services may come close to or even exceed the stated technological requirements for improved pavement striping materials. The new 3M products and services have been extensively evaluated and 3M is confident they can undersell and outperform current state-of-art materials and services. 3M's specifications for contract service and guaranteed striping materials.

Conclusions and Recommendations

The bulk of federal pavement marking R&D lies within the Department of Transportation, Federal Highway Administration and Federal Aviation Administration and the National Cooperative Highway Program. DOD R&D in this area is carried out by the Army and Air Force in coordination with the FAA. Navy R&D in this area appears to be dormant.

Key federal personnel identified are:

-Mr. Bill Williams
National Cooperative Highway Research Program
Highway Research Board
-Mr. Bernard Chaiken
Federal Highway Administration
-Mr. Fred Horne
Federal Aviation Administration
-Mr. Emil York
Department of the Army
-Mr. William T. Helm
Department of the Air force; and
-Mr. R.W. Drisko
Department of the Navy

All of these gentlemen indicated an interest in the ICMA - NASA Technology Applications Project and in further participation in efforts to meet urban requirements.

At this time, it seem appropriate to await the announcement of 3M's new services. The acceptance of the 3M services will determine the advisability of continuing NASA and/or ICMA action in this problem area.

It may also be desirable to have a meeting with the above federal personnel, ICMA-TAP personnel, NASA OTU personnel, and BSCP-TAG personnel to bring the ICMA-TAP up-to-date on the range of technologies and organizations. Such a meeting would facilitate ICMA interaction with other technology oriented federal groups. Also, NASA could better assess potential mechanisms for NASA technical inputs in this area.

The ICMA-TAP should obtain retrospective and current awareness searches from NCHRP's HRIS and TRAIS systems to keep itself up-to-date on R&D in areas of interest to cities.

APPENDIX A

Problem Statements, R&D Summary, and Other Background Information

PAVEMENT STRIPING

A. Need

A traffic line material which is long wearing, instant drying, reflectorized but non-glaring. easily removable

B. Background

At present street line markings (crosswalks, centerlines, directional arrows, traffic lane markings, safety islands, and edge lines) are applied to street surfaces several times a year because the existing traffic paint has an extremely short useful life. Repainting street markings several times per year is an extremely costly use of manpower. Also, men engaged in painting street lines impede traffic, and endanger their own safety.

Street lines are primarily used for safety of traffic, and when they deteriorate they no longer effectively serve this purpose.

Because present traffic paint does not dry immediately street markings must be barricaded, thus impeding traffic and creating a safety hazard.

C. Constraints and Specifications

1. Traffic line material should adhere to the street paving and have a useful life of at least three years, or even ten.

   could sacrifice for useful life

2. Material shall dry instantly upon contact with street surface to eliminate the need for barricading of streets.

3. Material shall be reflectorized without the addition of glass spheres.

   maybe 200'

4. Traffic lines shall be visable for 500 feet.

5. Traffic lines shall not produce annoying and dangerous glare.

6. Material must be capable of adhering and drying in atmospheric temperatures of +10°F. Temperature extremes of -20°F to + ~~100°F~~ +160°F must be tolerated in service.

application for 40° - 100° F.

7. Material shall be available in white and yellow colors.

8. Material shall be put in place with existing street striping equipment or equipment of a less expensive and less cumbersome nature.

9. Material must be resistent to oil, gasoline, rock salt, and calcium chloride.

10. Lines or roads must show up not only in dry weather but also when roads are wet.

11. Price of paint not to exceed $3.00 per gallon. Or more permanent material to cost $0.30 or less per square foot. $ / year of life / $ of application

12. No detrimental interaction with paving surfaces, tires, shoes.

13. Must be usable on any and all existing paving surfaces.

14. Should be visible in fog, utilizing existing street and car lights.

15. System should be reversible so that lines can be removed or neutralized to color of pavement at some time after installation.

16. Easily removable

D. Representative Available Equipment

E. Relevant Technology

Should restrict solution to paint.

P. P.S. for Review 4/71

DRAFT

Problem Statement SRI/T-61

PAVEMENT STRIPING

What is Needed

A pavement striping material is needed that is durable and reflective.

Background

Few pavement marking materials last longer than two years, some only two months. The markers may be abraded by tires, chipped by studded snowtires, dislodged by snowplows, or peeled by moisture and frost. Replacement of striping is expensive, striping equipment impedes traffic, and the workmen are endangered.

Marking materials are least effective during wet, dark periods, the times when a driver's need for guidance is most critical. Some materials fail to delineate even in dry daylight hours. Some commonly used materials and their shortcomings are listed below.

1. Paints, usually a modified alkyd or modified alkyd-chlorinated rubber type, require renewal, sometimes as often as every two months. They are effective markers during dry daylight hours but are almost obliterated during wet periods. They dry slowly, thus requiring dangerous, expensive barricades that impede traffic.

2. Paints containing glass beads improve nighttime visibility but do little to improve guidance during wet periods. Silicones, added to increase water runoff, last only a few days. In addition, the glass beads cause dirt and road film to accumulate on the marking, greatly reducing its daytime effectiveness.

3. Tape with or without a reflectorized surface lacks the long-wearing qualities needed.

4. Raised markers are effective delineators at most times, but are highly susceptible to damage from snowplows. (Spring-mounted and cast iron ramp reflectors have been developed to reduce this damage.) In addition, all raised markers must be removed during pavement resurfacing--an expensive, time-consuming procedure.

5. Hot thermoplastics, with glass beads extruded or sprayed, have proved very durable, with a life expectancy five to six times that of paint. However, they do not have the wet weather reflectance required and cannot be applied during cold weather. Some require an epoxy primer on the pavement, and removal of these markers before repaving is difficult.

Less common markers include low profile epoxy-glass bead markers and combined longitudinal grooving and striping. Because of restricted applicability, limitations in performance, cost, or a limited degree of development and practicality, most of the concepts above have not been fully accepted or utilized.

Constraints and Specifications

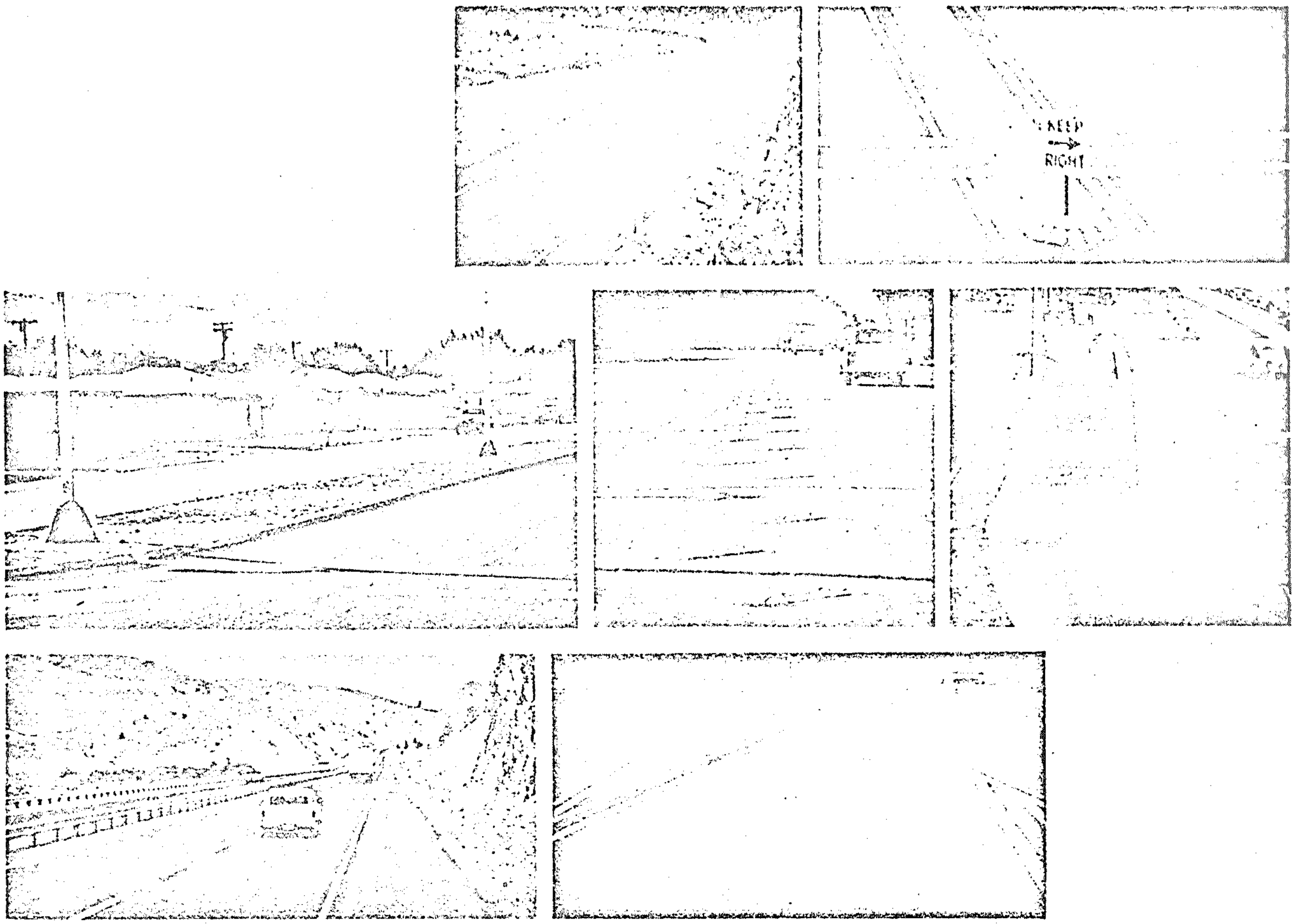
1. The material must be visible for 500 feet during daylight, nighttime, wet, and dry conditions on asphalt and concrete roads.
2. The material must have a useful life of over $2\frac{1}{2}$ years.
3. It must be resistant to oil, gasoline, rock salt, and calcium chloride.
4. The cost of the material should not exceed $0.30 per square foot.
5. To eliminate the need for barriers, the material should adhere and dry within several minutes at temperatures down to $10^{\circ}F$.

References

1. National Cooperative Highway Research Program, Report No. 45, "Development of Improved Pavement Marking Materials."
2. National Cooperative Highway Research Problem, Project 5-5B, "Pavement Marking Systems for Improved Wet-Night Visibility Where Snow Plowing is Prevalent."
3. National Cooperative Highway Research Program, Report No. 85, "Development of Form-in-Place Wet Reflective Markers."

For further discussion or information contact

Mr. Richard Blunt, Stanford Research Institute, Menlo Park, CA 94025
Area Code 415, 326-6200, Extension 3380



Traffic Marking Materials— Summary of Research and Development

Reported by[1] **BERNARD CHAIKEN,**
Principal Research Chemist,
Materials Division

BY THE OFFICE OF
RESEARCH AND DEVELOPMENT
BUREAU OF PUBLIC ROADS

Recent research in traffic marking materials is presented in this review to summarize the state-of-the-art since the last comprehensive bibliography published in 1952 by the Highway Research Board. It is intended not to present a complete bibliography on the subject since 1952, but rather, to point out the most pertinent research findings and developments in recent years. Research and development in the United States sponsored jointly by the State highway departments and the U.S. Bureau of Public Roads is emphasized and supplemented by information on other ongoing research by other agencies in the United States and throughout the world.

Many proprietary trade products are specifically mentioned to present a more complete account. Mentions of trade names are not to be considered endorsements of the products, nor are omissions of trade products, either overlooked or unknown to the author, to be considered inferences that such products are of lesser quality than those mentioned.

As MOST highway engineers realize, traffic marking has become a sizable item in the maintenance budgets of many highway departments. In a published survey (*1*)[2], it was shown that throughout the United States, in 1965, 12 million gallons of conventional traffic paint were purchased by the States and an estimated additional 9½ million gallons by cities and counties. Thus city,

[1] Presented at the 55th Annual Meeting of the American Association of State Highway Officials, Philadelphia, Pa., October 27-31, 1969.
[2] Italic numbers in parentheses identify the references listed on page 256.

county, and State governments nationally used more than 21 million gallons of conventional traffic paint. At average costs of $1.66 per gallon for white paint and $1.95 for yellow paint (*1*), the national cost for paint binder in 1965 alone was estimated at $38 million. It was also reported in the survey that approximately 107 million pounds of reflectorizing glass beads were purchased by these governments during the same year—66 million pounds by the States and an estimated 41 million pounds by cities and counties—at an estimated cost of about $12 million. Accordingly, the total cost of paint and beads during 1965 was approximately $50 million.

cost per year

But these material costs are reported to be only about a third of the total cost of installed conventional striping (*2*). Thus the annual overall cost of striping with conventional paint in the United States is estimated to be at least $150 million. This estimate does not include costs of other marking systems like hot thermoplastics, preformed stripes, or raised button-type markers, which are known to be appreciable. Not only these exorbitant costs, but also the need for adequate lane delineation to enable safe driving during all seasons of the year and in inclement weather, have stimulated pavement-marking research and development. The significant trends and developments in this field since the last comprehensive bibliography on pavement marking materials, published by the Highway Research Board in 1952 (*3*), is summarized in this review, which is intended not as a complete bibliography, by any means, but as a current state-of-the-art report to point up to present researchers and potential producers the most pertinent research and development in recent years.

In gathering information for this review, research and development in this country, particularly through Federally-aided highway studies (*4*) and similar experimental projects, was emphasized. In addition, information on recent international research, obtained through the Highway Research Information Service of the Highway Research Board, as well as available literature, reports, and unpublished information on domestic and international developments, were reviewed. Many proprietary products, which may not have been fully evaluated by unbiased consumers or governmental agencies, are specifically mentioned in this review. The mentioning of any product to provide the reader with a broader scope of developments is not to be construed as an endorsement of that particular product. Similarly, the names of many deserving trade products unknown to the author probably have been omitted.

HRIS

Conventional Solvent-Based Traffic Paints

The main objective of recent research and development in conventional traffic paints has been to improve durability and performance or to obtain more economical markings. Recent research activities include: studies of composition, as related to performance; special pavement pretreatments; accelerated laboratory tests to predict durablity; evaluation of the nature or cause of field failure; film thickness; and developments in reflectorizing glass beads. Each of these is discussed separately.

Composition

During the period from about 1940 to 1960, considerable research effort was directed at the pigment portion of traffic paint. In recent years, however, this aspect has received little attention from the State highway departments. Recent research and development effort on paint composition largely has been directed to the organic binder, commonly referred to by paint specialists as the nonvolatile vehicle. The most commonly used organic binder in conventional traffic paints purchased by State highway departments is the drying oil modified alkyd resin (*1*). Other vehicles used by these agencies in order of their decreasing prominence are: chlorinated rubber-alkyd, dispersion resins, phenolics, chlorinated rubber-petroleum hydrocarbon, and polyvinyl toluene polymer. A 1968 report by the Georgia Institute of Technology included results of laboratory and field tests on a wide variety of traffic paint formulations (*5*). The authors of that report concluded that oil modified alkyd, as well as chlorinated rubber-alkyd traffic paint, exhibited good performance—much better than most of the other types evaluated. In a separate report, it was shown by the New York Department of Transportation that, compared to a number of other conventional solvent-based paints, oil-modified alkyd paint gave the best performance (*2*). The New York Department of Transportation also conducted field tests and found that latex or emulsion-type paints did not compare favorably with their standard modified alkyd paint (*6*). The work in New York indicated that the latex paints had a useful life of only three or four months on either concrete or bituminous pavement. The latex paints performed poorly regardless of whether they were applied at ambient temperature or preheated and applied hot. Latex paints were also found to give poor adhesion in field tests reportedly conducted by the New Jersey State Department of Transportation (*7*).

Federally-aided research at North Dakota State University is currently being conducted on traffic paint vehicles that have the potential of reacting with the pavement substrate to provide good bond and durability. In this research, isocyanate-based paints are being studied for reaction with portland cement concrete pavement. At present, no significant trends have been reported. Current research at the Central Office of Public Roads in Poland is directed toward the development of polystyrene paints, but no conclusions are yet available.[3]

Special pavement pretreatments

In a 1957 study by Keese and Horn, it was reported that, compared to simple brooming or use of compressed air alone, sandblasting a portland cement concrete pavement to clean the surface prior to striping increased paint life substantially (*8*). In that study, sandblasting costs were reported to be 10 cents per linear foot. Regular cutting sand with an airflow of 210 cubic feet per minute and 110 p.s.i. compression was used for blasting. In a report issued by the New York Department of Transportation in 1969 (*2*), it was determined that neither acid etching nor synthetic rubber primer increased the durability of traffic paint on either concrete or bituminous surfaces, regardless of the ages of the surfaces. It was also reported that preheating the paint and applying it hot did not increase durability. According to a 1966 study by the Corps of Engineers, adherence of paint to portland cement concrete pavement can be improved by pretreating the pavement with a 50-50 mixture of boiled linseed oil and mineral spirits (*9*). It was shown in their field tests that, compared to an untreated test section, adhesion to the pretreated pavement was superior. This finding should be of value to northern States where concrete bridge decks are pretreated with linseed oil to prevent damage by deicing salt.

Laboratory tests and cause of traffic paint failure

For a great many years an urgent need has existed for an accelerated laboratory wear test that would accurately predict field durability and properly rank traffic paints according to their field performances. Over the past several decades, much research has been directed to developing such laboratory-wear or abrasion tests. Simulated traffic wheels, Taber abrasion tests, falling sand tests, and other methods have been tried, but none has gained universal acceptance because of poor correlation with field results. A recent additional effort by the Georgia Institute of Technology to develop a laboratory wear test that would correlate well with field performance (*5*) was unsuccessful. During 1968, research reportedly was underway at the Federal Institute of Road Research in Germany to develop an accelerated laboratory durability test.[4]

Apparently, some traffic paint specifications that are based solely on physical tests are unable to adequately assure good paint performance on the road. This fact was confirmed by a 1964 report by the U.S. Naval Civil Engineering Laboratory (NCEL) in connection with Federal Specification TT-P-85b (*10*), which is for reflectorized traffic paint for airfield runway markings. The NCEL report stated that mere conformity with the requirements of Federal Specification TT-P-85b did not guarantee a paint with good field service, nor did the test results obtained on a wide variety of conforming paints correlate well with field service. In particular, NCEL reported that the laboratory bleeding test was of little value in predicting field bleeding behavior. Specification TT-P-85b also stipulates a falling sand abrasion test to assure good

[3] Highway Research Information Service, Highway Research Board, Washington, D.C.

[4] Highway Research Information Service, Highway Research Board, Washington, D.C.

testing

durability, but the merits of this test are rather questionable on the basis of the NCEL findings.

Perhaps the major reason that abrasion-type laboratory tests have never become fully reliable or firmly established is that actual field failure involves a different mechanism. According to recent research results from an ongoing study by the State Highway Commission of Kansas, chipping or loss of adhesion, rather than abrasion loss, is a major cause of traffic paint failure on portland cement concrete. This observation, particularly with respect to concrete surfaces, was also noted by the Texas Highway Department and was reported in the literature by others some years ago (*11*). Work currently underway in Colorado confirms that traffic-paint chipping is a prominent cause of failure (*12*).

Paint film thickness

The most predominant wet film thickness of traffic paint used by most State highway departments is 15 mils (*1*). Use of this thickness may have become a general practice as a combined result of field experience and published research results. More than 10 years ago, the Michigan Department of State Highways, investigating the field performance of various wet film thicknesses from 12 to 21 mils (*13*), reported that the thicker films were more durable but that the additional life of paint thicker than 16 mils was not directly proportional to the additional thickness used. Accordingly, it was concluded that to increase the wet film thickness beyond 16 mils was not economical. Thus, the general practice of applying a wet film of 15 or 16 mils seems to have some substance. This practice is keyed to the use of conventionally graded glass beads.

In more recent work reported in 1965, researchers at the Georgia Institute of Technology reported that paint durability, and even night visibility, was improved as wet film thicknesses within the range of 10 to 20 mils (*5*) were increased. They specifically noted that wet film thicknesses of 10 mils were generally incapable of properly binding drop-on beading, presumably of conventional gradation. Their field work included a two-coat application of 15 mils each, which provided superior performance. However, it was postulated in the report that, for single-coat applications, 20 mils would seem to be the practical upper limit for the types of paints investigated. The Kentucky Department of Highways, experimenting with multiple film applications of 15 mils each, reported informally that multiple coats provided improved durability over a single 15-mil thickness, but that the comparative economics had not been fully established.

On the other hand, some of the research now being pursued seems to contradict part of these findings. For example, researchers at North Dakota State University, conducting a traffic paint study supported financially by the North Dakota State Highway Department and the Bureau of Public Roads, have stated that wet films much thinner than 15 or 16 mils are required for good paint adhesion and subsequent durability. This contention is based on limited field tests and on the premise that traffic paint fails more often through lack of adhesion than through abrasion. However, only limited field evidence has yet been presented to support this hypothesis. In an interim report on a study by the State Highway Commission of Kansas it was stated that both reflectivity and durability were increased when paint film thickness was reduced from 15 to 10 mils (*14*). This work is being performed in conjunction with an investigation of reduced bead application rates.

Hence, at present, evidence as to the optimum film thickness seems to conflict. Perhaps test conditions and even the bead application rate are some reasons for the different findings. The work in Kansas on films thinner than 15 or 16 mils was conducted on previously striped areas where remnants of the old stripe still remained under the newly applied stripe. Consequently, the thicker the new stripe, the more the older paint remnant lost its adhesion to the pavement. Moreover, where larger accumulations of old paint were evident, it was determined that chipping losses increased. The Kansas work also included an investigation of reduced bead application rate, which will be more fully considered in the next section.

The optimum film thickness of traffic paint may therefore depend on whether striping is applied to a previously unstriped area or to an area on which remnants or accumulations of old paint still exist under the new striping. In addition, it is becoming apparent that optimum film thickness is closely related to bead gradation and bead application rate.

Reflectorized beads

Small glass beads not only provide night visibility for traffic stripes but are reported to contribute as well to the overall durability of the paint binder (*5*). Within the last several years, considerable attention has been given to the role of traffic paint beads. A recent article by J. M. Dale, based on theoretical considerations, raised many questions about the adequacy of current State highway specifications for bead gradation and application rate (*15*). The parameters of glass beads, including the best index of refraction, are controversial factors, which fortunately are under intensive investigation at present.

In most State highway departments, the present practice is to use beads of a standard refractive index—1.50+ as opposed to 1.65 or more—and an application rate of about 6 pounds of drop-on beads per gallon of paint (*1*). Generally, the bead-size gradations range from a maximum of 20 mesh to a minimum of about 100 mesh (*15*). These common practices will now be examined in the light of recent research and development findings.

Regarding refractive index, the New York Department of Transportation reported that although the special 1.65+ index bead, measured instrumentally, gave slightly better initial reflectivity, the improvement was hardly noticeable to the driver, and the measured quantitative difference diminished and finally disappeared as the stripe exposure time increased (*16*). It was concluded that use of the standard index bead, 1.50+, at a savings of 2 to 3 cents per pound, was preferable. The results in New York were applicable to both concrete and bituminous pavements. In a recent report by the Colorado Department of Highways, similar results were cited (*12*).

The application rate of drop-on glass beads to traffic paint is another parameter that is receiving current research attention. On the basis of an ongoing research study, being conducted in conjunction with the study of films thinner than 15 or 16 mils, the State Highway Commission of Kansas reports that the beading rate could be reduced from 6 pounds per gallon of paint possibly to 4 pounds per gallon with no loss in reflectivity or durability and with resultant economic savings (*14*). According to theoretical considerations and practical laboratory tests, an intermediate bead application rate provides better reflectivity than either a very high or very low rate (*17*). In a recent report by the Colorado Department of Highways it was also shown that an application rate of 4 pounds per gallon was both more economical and more effective than a rate of 6 pounds per gallon (*12*). However in that work, other special parameters, such as special gradation and specially coated beads to afford a flotation feature, were involved.

Bead gradation is also undergoing research consideration. The current gradation specifications used by the State highway departments differ considerably. Generally the sizes specified range from a top size of 20 mesh (100 percent passing) to approximately 100 mesh size (*15*). Highway engineers are interested in obtaining an optimum gradation and more uniformity between the gradation specifications of the State highway departments. In the previously cited article by Dale (*15*), it is suggested that fewer than 30 percent of the beads of current conventional gradation for drop-on applications are effective when they are first applied. It is claimed that many of the beads of the small size fraction are immediately submerged in the paint and therefore are not initially effective. It can be argued that these submerged beads never become effective if the paint fails by chipping. On the other hand, if the paint wears out mainly through abrasion, the initially submerged beads become effective later in the life of the film. Previously cited research supports the theory that adhesion or chipping failure is a significant factor in the life of the paint film.

Field test results, reported some years ago for special gradations of glass beads obtained from a single source (*18*), indicated that coarse beads, 20 to 40 mesh, initially gave much higher reflectance than either fine beads, 40 to 100 mesh, or conventionally graded beads, 20 to 100 mesh. However, this superiority was not maintained for a long period. After about six months exposure, the reflectivity of the coarse gradation dropped below that of the other two gradations, indicating that the coarse beads ultimately are removed from the binder by traffic action, even though

lack of adhesion

they are initially more effective because a greater proportion is exposed at the surface. In recent studies it has been shown that coarse beads, 40 mesh or larger, are lost by the binder soon after installation because they are poorly anchored (*12, 14*). Conversely, the extremely fine beads, 80-100 mesh, sink into the paint and never become effective reflective units when the paint fails from chipping or lack of adhesion. Accordingly, without considering cost factors, the optimum gradation should be one that is between a maximum size of 40 mesh and a minimum size of about 80 mesh, provided that a conventional wet film thickness of 15 or 16 mils is used.

The Colorado field experiment cited earlier is now being conducted on uniformly graded beads of a narrower gradation range than conventional gradations (*12*). The beads contain a coating that gives them a flotation property that is claimed to make them float but be partially immersed in the paint film. Presumably this property allows more reflectorizing units to be available at the paint surface. In interim reports from the Colorado experiment, it is shown that the special beads applied at a rate of 4 pounds per gallon provide reflectance equal to or greater than that of the conventional beads normally used by the States, which are applied at a rate of 6 pounds per gallon. According to the Colorado report, use of the special beads at the reduced application rate provided significant cost advantages. After 10 months, field tests indicated no evidence of any serious reversals in reflectance or of poorer durability. These findings have been confirmed by the Nebraska Department of Roads which informally observed the performance of such beads. The Nebraska observers stated that the flotation feature seemed more important than closer grading, as beads of the same grading but without the flotation property did not provide the same high degree of reflectance.

One predominant factor for good reflectivity seems to have been established by the results of past and current research—a bead must be slightly more than one-half immersed in the paint binder to obtain maximum retroreflectivity at high incidence angles (*17*).

Rapid-Dry Traffic Markings

There has been a recent upsurge of interest in rapid-dry traffic markings among State highway departments. One reason for this interest is the desire to disrupt traffic flow as little as possible during striping operations on existing highways where traffic densities are increasing. Another reason is economics; the cost of placing and removing the traffic cones needed for conventional striping can be partly offset by using the more expensive quick-dry markings, which do not require protective cones.

Several years ago a study was conducted on the use of microwave energy to heat and quickly dry traffic paint after its application to the pavement (*19*). The method was adjudged technically unfeasible because it was difficult to maintain a sufficient high-energy intensity in the paint film owing to its dissipation into the pavement itself.

The use of plasticized sulfur, which is melted in a flame or kettle and hot-sprayed onto the pavement, is being investigated as a quick-set marking by the Phillips Petroleum Company. Another material that seems somewhat similar, called *Sullarzan*, was reported in the British literature (*20*), in which the following properties were claimed: It is obtained by polymerizing sulfur (it may, in fact, be a mixture of polysulfide polymer and unpolymerized sulfur); it is available in solid granular form; it was developed by the Société Nationale des Petroles d'Aquitaine and is being introduced for trial in France and England; it is available in any color, presumably is applied in molten form, and dries, or sets, to a no-pick-up condition in 15 seconds; it contains glass beads and may even be applied to *wet* or *icy* roads (the latter claim is rather difficult to believe) and its covering rate is 400 grams per square meter. Its producer claims high durability—"6 times the durability of existing road marking materials." No evidence of rigorous and conclusive field research on the merits of sulfur-based markings by highway agencies is known to the author.

Several fast-dry, solvent-based paints were introduced in the last decade, one of which is the *Nite-Line* paint produced by Prismo Universal, Inc. Claimed to dry in 3 minutes or less, the paint is heated to 165°F and is applied by spray from special equipment. Glass beads are blown by compressed air into the wet binder. Application speed is said to be 8 m.p.h., and no traffic cones are used when the material is applied to the pavement. A follow-up truck about 500 yards behind the application truck temporarily keeps traffic off the wet stripe until it dries. The cost of the material, including glass beads, is about $6 per gallon. Reportedly, this product has been used in New York City and Baltimore, as well as in Pennsylvania, Florida, and Arkansas. In a recent article, it was reported that the Michigan Department of State Highways used a heated fast-dry paint, which may be similar to the above-mentioned product (*21*), except that the dry time claimed in the Michigan application was 1½ minutes rather than 3 minutes.

A similar fast-dry paint product, called *Green-Lite Liquid Striping Compound*, is being sold by the 3M Company. This solvent-based paint has a high solids content and is heated to 250°F and applied by airless spray. Dry time is claimed to be only 2-20 seconds, or an average of 10 seconds. The striping equipment can be purchased. The material contains pre-mixed beads and is applied at a wet-film thickness of 15 mils, which provides a dried film of about 11 mils. The producer claims that the material reacts with the air immediately when it is sprayed and that this aids in speeding up the dry time. Again, no protective cones are required for application. The durability of the paint is said to be equal to that of conventional striping, and material costs are about $8 per gallon. The maximum speed of the striper is 10 m.p.h. The company states that this material is being tried out in Florida, Michigan, Missouri, California, and Colorado.

Similar heated, fast-dry proprietary paints, such as *Hot Line* produced by the Baltimore Paint and Chemical Corp., are also available from other producers. Within the last year or two, the Texas Highway Department has been experimenting with a fast-dry, heated paint based on chlorinated rubber, chlorinated paraffin, and alkyd resin. The paint has a low solvent content and requires only moderate heating. The needed heat can be obtained from the liquid cooling system of the engine on the striping truck, thereby eliminating the need for special auxiliary heaters like those used for some of the other proprietary fast-dry, heated paints. This material is applied by airless spray and reportedly dries in 2 minutes when heated to about 120°F, or alternatively dries in 4 or 5 minutes when applied without heating. Material cost of this paint is estimated to be about $2.30 per gallon. This material may be fairly similar to the British product called *Clearlane*.

Several other types of proprietary products have a rapid, almost instant, setting property. These include the hot-extruded thermoplastic striping and hot-sprayed plastic materials that are applied as rather thick coatings. However, because such materials were primarily developed to provide long-lasting stripes, they will be discussed more fully in the following section.

Semi-Permanent Markings

Materials that have been developed to serve as semi-permanent markings include preformed glue-down plastic stripes, hot-extruded and hot-sprayed thermoplastic stripes, and plastic or ceramic raised button-type markers. Compared to conventional stripes, they were developed mainly to provide long-range economic benefits, although the raised button-type markers are also intended to provide improved visibility in rain or fog.

Preformed glue-down plastic stripes contain an adhesive backing and are mainly used on bituminous pavement in high-density urban areas—usually for crosswalks and stop lines. Their use on open highways has been rather limited. A report by the Arkansas State Highway Department indicated that such materials do not provide adequate durability, mainly because their adhesion to concrete surfaces is poor (*22*). Somewhat better performance was reported when the material was applied to bituminous surfaces. Installed costs on a contract basis were stated to be 55 cents per linear foot of 4-inch-wide stripe. A research report by the New York Department of Transportation similarly indicated poor durability on open highways because the material was quickly dislodged and destroyed by traffic and snowplows (*23*). Proprietary products of this type produced in this country include *Plastix* and *Neff-Slabs*. An apparently similar material, called *Verynl*, was investigated by the New Zealand Transport Department in 1968. This material is claimed to have good wear and to be more economical than paint for pedestrian cross-walks. *Verynl* contains polyvinyl chloride, is 2.5 mm. thick, and is applied with standard mastic. It was

rapid drying

durability

reportedly tried out in this country in Los Angeles.

There has been considerable research in this country on *hot-extruded thermoplastic stripes*, which are applied at a thickness of about one-eighth inch. Such materials are sold under the trade names of *Permaline* and *Catatherm.* A comprehensive survey and report on these materials, prepared this year by the Bureau of Public Roads (*24*), was based on the results of a large number of installations throughout the United States. The major conclusion and recommendations in that study were as follows:

- Hot-extruded thermoplastic materials were much more durable on bituminous pavement than on concrete pavement. The material is more durable on older concrete than on new concrete.
- Snowplow activity dislodged the material from the pavement, particularly on concrete.
- A factor limiting the economic value of thermoplastic striping on bituminous pavement is the limited maintenance-free life of the bituminous surface.
- Unremoved layers of old paint adversely affect the adhesion of thermoplastic striping to the pavement.
- Under conditions of little or no snowplow activity, thermoplastics were found to be more economical than paint striping, provided the traffic density was appreciable. For bituminous pavements, the daily density should exceed 6,000 vehicles per lane; for concrete pavements, the density should exceed 9,000 vehicles per lane. Under conditions of moderate snowplow activity, the use of thermoplastics could be justified, provided that traffic density levels are high enough. Finally, under conditions of severe snowplow activity, there is little economic justification for the use of hot-extruded thermoplastics.
- Guidelines in the report enable the selection of the most economical material—paint or thermoplastic—for different traffic densities and degrees of snowfall.

An interesting sidelight to investigations of thermoplastic striping materials is a 1965 report by California (*25*). Contrary to some beliefs, it was shown that thermoplastic striping presented no substantially greater skidding hazards than conventional striping.

Thick coatings of hot-sprayed plastic material for semi-permanent markings is a comparatively new development, exemplified by the proprietary product called *Hot Spray Plastix.* This hot-sprayed material, applied at a thickness of 90 mils, costs approximately 21 to 26 cents per linear foot for 4-inch-wide stripes and hardens in seconds. At present, experience has been more limited with this material than with hot-extruded thermoplastics. The product is being tried in Philadelphia, on the Penn-Lincoln Parkway near Pittsburgh, on I-495 near Washington, D.C., and on various expressways in and around New York City.

Raised button-type markers are also a form of semi-permanent marking, but because they also serve to improve night-wet visibility, they are discussed in the following section.

Markings for Improved Night-Wet Visibility

Raised button-type markers, used widely in some of the far western States, notably Washington and California, actually serve two purposes: they are long-lived and therefore economical, and they provide excellent night-wet visibility. Their use has been limited largely to areas that are free from snow and snowplow activity. Raised markers are used extensively in the snow-free areas of California (*26*). Patterns of four white nonreflective markers placed 3 feet apart are separated by 15-foot gaps. One reflective-type marker is placed in each gap on curves and in alternate gaps on tangents. According to the California Department of Public Works, the best reflective marker in use is an acrylic or ABS plastic-encased corner cube reflector. The Department's experience indicates that the raised marker is much more durable than conventional paint. The Washington Department of Highways also has reported good experience with raised markers in snow-free areas (*27*). Raised markers were reported to be superior to standard traffic paint in terms of durability, driver preference, and night-wet visibility, and their cost for a 10-year period was claimed to be compatible with the cost of standard paint striping. The annual cost of marker maintenance was one-fourth that of paint-striping maintenance. The California Department of Public Works recently reported on the development of a rapid-set epoxy adhesive for raised markers (*28*), which is based on the use of a polymercaptan curing agent that cures epoxies in thin films at a rate that is 7 to 10 times faster than the conventional curing rate of epoxies. The new adhesive can be used at temperatures lower than 30° F.

Raised markers perform poorly in snowy areas that are subjected to snowplow activity, as proved by experiments in Arkansas (*22*) and California (*29*), in which raised buttons failed badly. In California, failure occurred even when precast markers were inset in the pavement to obtain a lower profile. Poor performance in snow areas was also evident when epoxies were cast and cured-in-place in cut-out pavement sections that were finally finished off flush with the pavement surface.

When applied in snow-free areas, raised button-type reflective markings have substantially solved the problem of good night visibility under wet weather conditions. Present emphasis in research is to extend this solution to the snow-belt area of the country and also, if possible, to develop more economical and durable systems. In an interesting research study just completed in the State of Washington, regular raised markers were used in a snow-belt area, and snowplow blades were equipped with neoprene rubber bits to prevent marker damage. During two winter seasons at three separate test sites, the synthetic rubber bits were effective in removing snow except when the temperatures consistently remained below freezing. When semi-thawing conditions existed or could be induced by deicing chemicals, the rubber-tipped plows were very effective. Although initial costs were higher, the rubber bits did not wear out as quickly as steel bits and actually cost less per mile plowed. The most interesting part of this experiment was that few raised markers were lost at the test sites. At one site with concrete pavement, marker loss attributed to the rubber-tipped plow blades was from 1 to 2 percent during one winter season. At another site with bituminous pavement, marker losses were from 3 to 5 percent for a single winter. At the third site, no definite count was made, but the State reported from informal observations that little marker loss occurred in one winter.

Another development to obtain night-wet visibility in northern States where snowplow operations are extensive is the so-called *snow-plowable*, raised, reflective marker under investigation in both Pennsylvania and Texas. The reflective element is a high strength acrylic plastic that is based on corner-cube retroreflection and is contained in a steel casting with two keels. The keels are cemented with epoxy resin into grooves cut into the pavement. The casting also contains protective runners that direct snowplow blades over the marker, presumably without damage. The marker is installed in the skip zone between dashed stripes, generally in every other skip zone on tangents and each skip zone on significant grades and on horizontal curves. The estimated installed cost of each marker is approximately $4, and the replacement cost of each reflective element is estimated at 25 cents. The Texas project was recently initiated but the Pennsylvania installation on the Schuylkill Expressway in Philadelphia has been in progress since 1967. Informal reports on the latter investigation indicate that although very little snowplow damage occurs to the steel castings, the plastic reflectors have been badly damaged.

Other ideas for more economical, snowplow-resistant systems for night-wet visibility are being investigated in an ongoing study at the Georgia Institute of Technology that is sponsored jointly by the State Highway Department of Georgia and the Bureau of Public Roads. Researchers are looking into the possibilities of a corrugated or textured hot thermoplastic stripe containing beads. The thought behind this work is that the peaks of the corrugated thermoplastic stripe will not be immersed in water during heavy rains and, thereby, will provide retroflection in wet weather. The study also includes use of reflectorized aggregate chips in a suitable binder to obtain the same results. Two test sites, one snow-free and the other subject to snowplow activity, will be used in the investigation. Performance will be compared with conventional raised markers.

Another approach to the night-wet visibility problem is under study in the National Cooperative Highway Research Program managed by the Highway Research Board. This study, NCHRP Project 5-5 entitled *Nighttime Use of Highway Pavement Delineation Materials*, is in progress at the Southwest Research Institute. It deals with the use of

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quarter-inch-diameter glass beads that are dropped into a cast-in-place epoxy marker, which is then allowed to set and harden. The large-bead concept was developed in a preliminary phase of the same study (30). The researchers had developed the concept that one-quarter-inch diameter beads half-imbedded in an appropriate binder will provide a profile that will not be completely inundated by a film of rain water and, thereby, will provide adequate night-wet visibility. The researchers believed that this concept would be less expensive than commercial raised markers and that the lower overall profile would be subject to less damage by snowplows. In the current phase of the study, a road machine that casts the epoxy, deposits the beads, and then moves on to the next marker location was developed. Installations of this type have been placed in Texas, California, New Jersey, North Carolina, and Florida. The study is to be completed shortly and the final report is under review.

In another novel experiment to obtain improved night-wet visibility now being conducted by Utah State Department of Highways (31), small longitudinal grooves are cut into concrete pavement to an overall width of 4 inches. At intervals, transverse grooves are cut across the longitudinal grooves to provide positive rain water drainage away from the longitudinal grooves to the low side of the crowned pavement surface. The longitudinal grooves generally are a quarter-inch deep. The grooving is then striped with conventional reflectorized traffic paint. Theoretically, the grooved striping will be more durable than conventional striping, as it is recessed and not subjected to traffic and snowplow abrasion. More importantly, the stripe should be more visible in rainy weather than conventional striping because rain water is drained away from the reflectorized grooved surfaces. The study is still in progress and no data are yet available on the relative economics of such striping, although recent indications are that the life of the grooved striping is better than that of conventional striping. One important development so far is that the grooved striping is more visible than standard striping during a rainstorm—either at night or during the day. The study will include several different grooving designs to determine the one that gives optimum performance. In addition, the State highway department has suggested that grooves be formed in a newly placed pavement—either fresh concrete or hot bituminous pavement—and has offered appropriate plans. There is considerable interest in this experiment from the standpoint of a snowplow-resistant marking that can provide night-wet visibility. As a result, at least two other States, New York and California, plan to investigate this approach.

Temporary Lane Markings

Temporary lane markings for construction detours are of interest to many State highway departments. In 1961, a machine used by the Missouri State Highway Commission to erase temporary stripes was described in the literature (32). Containing a 9-horsepower engine equipped with 92 steel cutters, the machine cost $758. It could operate at speeds as high as 10 feet per minute. The cost of each steel cutter was 20 cents and each could last as long as four working hours.

More recently, in 1965, the Michigan Department of State Highways reported an evaluation of temporary removable lane marking tape (33). It was claimed that grinding equipment to remove temporary paint was not fully effective and that paint residues remained to confuse the driver. The evaluated tape is 20 mils thick and is available in 4- to 6-inch-wide rolls. The core is soft aluminum and the top is a white or yellow beaded vinyl material. The backing contains a pressure-sensitive asphaltic adhesive and is used in conjunction with a pavement primer to promote good adhesion. It is recommended for use as a temporary marking instead of conventional paint, which is both difficult and costly to remove. The Massachusetts Department of Public Works, as a result of its own study completed in 1968, also recommended use of removable tape for temporary lane markings. The tape was compared with a water-based temporary paint and determined to be much more preferable.

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i considerable penetration of the prime coat into the wood. Two-coat systems should not be used to save paint, but should attempt to give the same film thickness as a three-coat system.

Before paint is applied, it should be well stirred and thinned according to directions. ɔ standard thinning instructions can be given, because the amount of thinner needed ..ries with formulation of the paint and because of other factors. Usually the first, or prime, coat should contain more oil and be thinner than the second coat. The second coat ordinarily should contain more oil and be thinner than the top coat. The ɔre absorptive the surface, the greater the quantity of oil that should be used in ducing the paint. A high gloss is to be avoided on any coat to be repainted, which may call for reducing with less oil and more volatile thinner. More thinners are used in cold-weather painting to give the paint proper brushing characteristics. In two-at painting, the procedure is essentially the same as in three-coat, except that the ɔdy coat is omitted.

A paint system, whether a two-coat or a three-coat one, may use a special primer paint. Such primers usually have the vehicle reinforced with a small amount of resin. They are designed to overcome the nonuniform absorptive characteristics of wood and e especially valuable in two-coat systems.

3. Paints. Paints for wood are usually formulated with linseed oil as the binder. In recent years, paints have been formulated using other oils alone or in combination with linseed oil and with or without resin fortification. However, users of highway aints usually prefer the linseed-oil types which have been proved in service for many ears. Raw linseed oil is widely used, and a combination of about 92 per cent alkali-refined linseed oil with about 8 per cent kettle-bodied linseed oil is also popular. The bodied oil is added for improved durability, and is usually specified to be of "Q" body n the Gardner-Holdt scale. The use of alkali-refined oil assures more uniform consistency for any given formulation than when raw oil is used. Driers are added in the amount of about 0.6 per cent lead and 0.02 per cent manganese, calculated as metal and based on the nonvolatile vehicle of the paint.

In the past these paints were generally formulated at a pigment volume (PV) of 28 30. However, during the war and as a conservation measure, the linseed-oil content was reduced and the pigment volume thereby increased. It has been found that pigment volume can vary quite widely without serious effects, and specifications in some cases still specify the higher pigment volume. However, in general, high pigment volumes tend toward excessive chalking while low pigment volumes tend to produce paints which collect dirt and fail by checking and cracking. It is always the object in paint formulation to balance these factors and produce materials which will chalk sufficiently to be self-cleaning and provide a good surface for repainting but which will not show early failure from excessive chalking.

E. Traffic Paints

Traffic paint is a tool of the traffic engineer used as an aid in making highways safer and more efficient. It has little protective value and differs from most other paints in this respect. It also differs from other paints in the fact that it is relatively new and has not been standardized to any degree comparable with protective paint for steel and wood. Increase in the use of traffic paints has been so rapid, the volume used annually has become so great, the service conditions are so severe, and the need for economical materials in terms of service cost is so apparent, that the problem of formulating adequate paints of this type remains a challenge to material manufacturers, paint producers, highway organizations, and research agencies alike.

1. Traffic-paint Requirements. Traffic paints are required to meet service requirements not demanded of any other type of paint. They must be thin enough to flow or to be sprayed readily, have high hiding power, show good adhesion for a variety of surfaces, have good resistance to abrasion, have good visibility and color retention, resist weathering, not discolor when applied on bituminous surfaces, be resistant to water and alkali, and be skid-resistant and dry in a matter of minutes.

Composition requirements of traffic paint depend upon the specification and may include percentage pigment, percentage vehicle, type of pigment, type of vehicle, total solids, and weight per gallon.

Drying time of a traffic paint is important because the line must be protected until the dry to "no-pick-up" condition is reached. The ASTM has standardized a Test for No-pick-up Time, D 711-55, No-dirt Retention Time, D 1297-56, and No-smear Time, D 1359-55T.

Consistency requirements are determined by the method of application. Consistency should be determined for the particular paint and method of application to be used and then held within reasonably narrow limits of this value by controlling composition as well as application characteristics. The ASTM Test for Viscosity of Paints, Varnishes and Lacquers by Ford Cup, D 1200-54, is commonly used for this control.

Bleeding is a condition where the paint absorbs asphalt or tar from the surface, causing discoloration. It is controlled principally by the type and amount of solvent used in the paint. This property can be checked by ASTM tests, Evaluating Resistance to Bleeding, D 868-48, and Laboratory Test for Bleeding Resistance, D 969-54.

Settling characteristics of traffic paints are of concern because their thin consistency and the use of coarse pigments to improve visibility make them particularly susceptible. Standard ASTM tests are Evaluating Settling, D 869-48, and Settling Properties During Storage, D 1309-56.

Visibility of a traffic paint is frequently determined by judging an actual line by eye under day- and nighttime conditions. However, portable night-visibility instruments are available. Good visibility is essential and is obtained by the use of coarse pigments or glass beads.

Durability is a prime requirement of traffic paint and the factor that receives most attention from the standpoint of possible improvement. It is determined not only by the paint, but also by the character of the surface to which it is applied and by conditions of application. Resistance to water, and particularly the effect of water on adhesion to the pavement, is important to durability in many cases. Type and amount of traffic, location of the line on the road, etc., are other durability-determining factors. The relative durability of traffic paints can be rated satisfactorily by the use of transverse lines for observation under traffic. This is true particularly when the test stripes are placed on narrow pavements or in locations where traffic is channelized and different portions of the line are subjected to extreme variations in the amount of traffic. Abrasion and erosion characteristics are evaluated by ASTM Method D 821-47.

2. Types of Traffic Paints. Traffic paints may be classified on the basis of the type of surface for which they are intended or on the basis of the type of vehicle employed. They are usually white, yellow, or black. The same vehicle may be used for each color, but often black traffic paints have an asphalt or tar base.

On the basis of types of surface for which they are intended, traffic paints may be divided into two classes:

1. Those for concrete and brick where bleeding is not a problem
2. Those for asphalt and tar surfaces that are likely to bleed

Although some thought has been given to the development of a greater number of paints on the basis of this classification, the tendency at the present time is to develop all-purpose paints for use on any road surface.

On the basis of the type of vehicle employed, traffic paints may be classified into three general classes:

1. Cold-cut vehicles using natural resins dissolved in suitable solvents and plasticized with various oils (spirit-type paints)
2. Vehicles containing resins and nitrocellulose (lacquer types)
3. Varnish vehicles of varying oil lengths with natural or synthetic resins modified with drying oils and/or other materials such as rubber (cooked-vehicle paints)

Some paints now in use would have to be classified as special cases of the last group. Also, thermosetting synthetic materials have been used, and new materials which possibly would not fit this classification are possible at any time.

Natural resins and synthetic products that have been used in traffic-paint vehicles include ester gum, Manila, Batu (East India), Congo, coumarone-indene, alkyds and their modifications, phenolics and their modifications including dispersion resins, pentaerythritol resins, copolymers of styrene and butadiene, chlorinated rubber, and zinc resinate.

Pigments used in traffic paints include some not ordinarily used in paints of other types. Covering or hiding is usually obtained with titanium pigments or zinc sulfide pigments in white paints. Anatase titanium barium pigment has been used in the past, but the rutile titanium calcium variety is now being used. CP chrome yellow of the desired shades is used as the hiding pigment in yellow traffic paints. The hiding pigment in black paints of the oleoresinous type is usually carbon black.

Zinc oxide is frequently used as part of the pigment in traffic paints. It offers some hiding value, but is used chiefly for faster drying and to give the film better abrasion and weather resistance.

The inert or extender pigments include magnesium silicate, barium and calcium sulfate, calcium carbonate, silica, micaceous materials, and pumice. They are used to give balance to film properties and for night visibility.

3. Specifications for Traffic Paints. Specifications for traffic paints are of four types:

1. Composition specifications
2. Specifications based on physical tests
3. Specifications based on service tests
4. Combinations of the above

Composition specifications specify in detail the type and amount of each ingredient of the paint. The quality is fixed by the purchaser, who assumes responsibility for durability. General clauses providing for good workability, lack of hard settling, etc., are used to throw some responsibility for a good product on the supplier. Traffic paints of the so-called "spirit type" using a cold-cut natural resin represent a type particularly adaptable to the composition type of specification. Composition specifications are not as desirable for more complex paints involving the processing of a "cooked varnish" because performance may be determined as much by skill of processing as by the ingredients used.

Specifications based on physical tests require that the purchaser have knowledge of the properties of a paint film necessary for good performance and the tests that will measure them. This type of specification has much merit in that it inherently provides the opportunity for the progressive producer to supply a superior product. It requires, however, that fully reliable accelerated test methods be available which will accurately predict performance. Unfortunately, such test methods are not completely reliable at the present time. Federal Specification TT-P-115a may be classed as this type, although quality is controlled by a comparison paint.

Specifications based on service tests allow for selection of the best material submitted by suppliers as determined by a service test conducted by the producer. Such a specification has considerable merit in that it requires no knowledge of paint ingredients on the part of the purchaser and automatically keeps pace with new developments. It is subject to the limitation that several months' time is required for testing and also that there is no positive assurance the material supplied will be of the same quality as that which was tested.

Combined specifications, those using two or more of the basic methods cited, are the most popular. Composition specifications usually provide for physical tests on the vehicle, the finished paint, or both. Specifications based on physical tests may specify a comparison paint or may specify one or more of the ingredients. Specifications based on service tests usually also provide for physical tests, and perhaps for an analytical procedure, on the material supplied as a result of service testing.

4. Formulation of Traffic Paints. Traffic paint is required to meet so many special requirements that each formulation represents a compromise between desirable characteristics. The relationship between drying time and durability is a case in point. With many types of traffic paints in use, drying time and durability are a function of pigment volume (PV). In order to meet drying-time requirements, paints are often formulated with a PV of 50 per cent, even though they show much better durability when formulated at a PV of 40 per cent or even lower. With technical advances, good hiding or covering power can now be obtained with less pigment, opening the way for increased durability by the use of less pigment if drying time can be decreased by other means. Such advances have also allowed more judicious use of inert extender pigments to obtain such properties as optimum porosity (to permit passage of water vapor and prevent blistering) and better visibility, in addition to increased durability.

The specification of the Virginia Department of Highways for No. 40 White Traffic Zone Paint, Reflectorized, which has been found to give very satisfactory service (43), is given in Appendix D.

5. Application. Traffic paints may be applied by brush, spray, or flow methods. The paint should be formulated for the type of application that is intended. Brushing dislodges dirt and works it into the paint film and promotes adhesion. Flow applicators with which a brush is employed also accomplish this action to some extent. When spray methods are used, it is necessary that the surface be as clean as possible, and the paint should be formulated for good wetting characteristics. Most paint is applied by spray methods. Machines have been developed which will place, one, two, or three lines simultaneously and will place either a solid or a dashed line. They will do this at rates as high as 15 mph. Traffic paints are applied at the rate of 10 to 30 gal per mile of 4-in. line, depending upon the character of the surface. Rough surfaces require more paint. Usually a rate of 15 to 20 gal per mile is used, which corresponds to spreading rates of about 120 to 90 sq ft per gal. If the paint is well formulated and other factors are equal, thicker films give longer service.

6. Use of Glass Beads. The use of glass beads for night visibility is probably the most significant advancement in the use of traffic paints. Retroreflection of the painted line is so outstandingly superior when glass beads are used that the traveling public is demanding this type of reflectorized line to an ever-increasing extent. The beads may be dropped onto the wet paint film, or they may be mixed with the paint before application, or both. Usually 4 to 6 lb of beads per gal of paint is used, except that for airports the rate may be somewhat higher. If mixed with the paint, a period of wear under traffic is necessary before the beads become fully effective. If the beads are placed on the wet paint film, spreading rate or film thickness must be closely controlled. If too little paint is used, the beads will not be retained; if too much is used, the beads will be covered and will lose effectiveness.

Paints for use with glass beads must be formulated with vehicles that have good adhesion for glass. Such paints also are normally formulated at pigment volumes about 5 per cent lower than otherwise would be the case, to allow for the vehicle which is used to wet the beads. Such factors as paint consistency, drying time, and amount of volatile thinner are important to bead retention.

Beads for use on traffic paints should be of translucent glass and as spherical in shape as possible. Cloudy beads are inferior. The glass must be resistant to weathering, particularly to surface etching, which destroys its reflective value. Beads must possess sufficient crushing strength. They are usually graded to produce maximum reflectivity over the life of the paint.

A typical specification for the drop-on type of beads is given in Appendix E.

X. LUBRICATING OIL AND GREASE

Lubricating oil is generally a highly refined mineral oil from either paraffinic or naphthenic base crudes. It is important that the proper crude be selected in order that the finished product will not only perform its primary function of reducing friction but also maintain a degree of chemical stability over an extremely wide range of operating conditions.

Basically, lubricating oil is composed of an infinite number of different hydrocarbon molecules, some of which are not suitable for lubricants and are removed by modern refining methods. This alone does not ensure satisfactory performance in many instances, and it is necessary to incorporate certain additives to improve the natural characteristics of the lubricant. Higher operating temperatures, heavier loads, faster sufficient strength to resist stripping the reflective sheeting from the base material to which applied when tested with a putty knife; shall resist scuffing and marring during normal handling; shall maintain elasticity at low temperatures to resist shocking off when struck at 20°F; and be capable of soaking in water for eight hours at 75°F without appreciable decrease in adhesion. The pre-coated adhesive shall have no staining effect on the reflective sheeting and must be mildew resistant. A protective liner shall be provided to prevent contamination and premature adhesion of the precoated adhesive and the liner shall be removable by peeling without the necessity for soaking in water or other solvents.

Sec. 246.03 Optical Properties. Reflective sheeting shall have the following minimum brightness values at 1/5° divergence, expressed in units of candle power per foot-candle per square foot.

Angle of incidence	Color				
	Silver	Yellow	Red	Blue	Green
0°	27 CP	10 CP	7 CP	3.0 CP	2.5 CP
30°	15 CP	5 CP	4 CP	1.4 CP	1.2 CP

The brightness of the reflective sheeting, totally wet by rain [Military Specification MIL-R-13689 (CE)], shall not be less than 80 per cent of the values specified.

Measurements shall be conducted in accordance with standard testing procedures for reflex reflectors of the Society of Automotive Engineers.

Sec. 246.04 Physical Properties. Reflective sheeting shall be free from ragged edges, cracks, scale, discoloration, and blisters and sufficiently flexible to permit application over and conformance to moderate, shallow embossing characteristic of certain sign borders and symbols. It shall be moisture resistant and readily adaptable to cutting with scissors, knife, blade, or shears without cracking, checking, or flaking.

Sec. 246.05 Durability Guarantee. The material supplied under this specification shall be guaranteed by the supplier to show no more than 10% loss in brilliance each year for a period of four years. Material which fails to give satisfactory service over a four year period shall be replaced by the manufacturer on a pro rata cost basis.

Sec. 246.06 Samples. For each color specified the bidder shall submit with his bid a square foot sample of the material which he proposes to furnish under this specification.

From each shipment of material samples shall be taken at random. These samples shall maintain the standards set by the material submitted with the bid. (Apr. 1, 1958.)

D. Virginia Department of Highways, Specifications for No. 40 White Traffic Zone Paint Reflectorized

No. 40 White Traffic Zone Paint, Reflectorized is a white paint for traffic line marking on highways, on which will be applied properly graded glass beads.

It is intended that this paint shall bind properly graded glass beads in such a manner as to produce maximum adhesion, refraction and reflection. (Beads to be placed on freshly applied line at the rate of 6 pounds of beads to 1 gallon of paint. Wet film thickness of paint to be .015 inches.) The capillary action shall be such as to provide adequate anchorage and refraction without excessive envelopment of the beads.

Composition	*Per Cent by Weight* Min.	Max.
Vehicle	40	
Pigment		60
Titanium dioxide	24	26
Calcium carbonate	30	32
Barium sulphate	30	32
Magnesium silicate		16
Coarse particles and skins (total residue on No. 325 sieve based on pigment), maximum 0.5 per cent.		

The vehicle shall consist of pure alkyd resin, thinners and driers. It shall be free of other synthetics or natural resins. The non-volatile content shall be not less than 45% and shall be a glycerol phthalate alkyd containing a minimum of 24% phthalic anhydride based on the vehicle solids. The alcohol portion shall be limited to glycerine and the oil portion to refined soya bean oil. The vehicle shall be so processed as to provide a product with an acid number of five maximum and color of seven (Gardner—1953) maximum based on resin solution at 60% non-volatile. The volatile portion shall contain not less than 20% of a high solvency thinner (Amsco A type).

The weight per gallon of the paint shall be not less than 13.2 lbs.

It is required under this specification that the color after drying shall be a pure flat white, free from tint, furnishing the maximum amount of opacity and visibility under both daylight and artificial light. The fixed drying oils used shall be of such character as will not darken under service or impair the color and visibility of the paint.

The paint furnished under this specification shall, when applied at the rate of .015 inches wet film thickness, dry sufficiently within one hour after application so that it will not be marred under traffic.

Forty-eight hours after this paint has been prepared and put in containers it shall have a consistency of from 80 to 85 K. U. as determined with the Krebs Modification of the Stormer Viscosimeter. An initial viscosity of 80 to 82 K. U. is desired.

A cleaned panel of tin plate (No. 30 U.S. standard plate gauge) three inches by five inches shall be coated with a film of the paint, having a wet film thickness of six thousandths (.006) of an inch, and baked for six hours in an oven maintained at a temperature of one hundred degrees Centigrade. The panel shall be allowed to cool at room temperature for one hour and shall then be bent rapidly around a one-fourth inch rod. The paint film shall withstand this test without checking, cracking, or flaking.

The paint shall show no skinning when a half pint friction top can is half filled, the lid replaced and then allowed to set for eighteen hours.

The color, hiding power, and flatness of the paint furnished under this specification shall be equal to that of a sample mutually agreed upon. When dry it shall show a flat, white, opaque finish, and shall show no graying nor discoloration when exposed to the equivalent of direct summer sunlight for seven hours.

A quart sample of paint which the manufacturer proposes to furnish under this specification shall accompany each bid. No bid shall be considered if the sample submitted therewith does not meet fully the requirements of this specification. (Apr. 1, 1958)

. Virginia Department of Highways, Specifications for Glass Beads for Reflective Traffic Paint Surface

General. This specification covers glass beads for application on traffic paint for the production of a reflective surface.

Material. The beads shall conform to the following requirements:

(a) The beads shall be manufactured from glass of a composition designed to be highly resistant to traffic wear and to the effects of weathering.

(b) The beads shall be spherical in shape, and shall not include more than twenty-five per cent of irregularly shaped particles when tested as described in Section 245.05, below. They shall be essentially free of sharp angular particles, and particles showing milkiness or surface scoring or scratching.

(c) Gradation. The beads shall meet the following gradation requirements:

U.S. standard sieve	Per cent	
	Minimum	Maximum
Passing #20, retained #30	5	20
Passing #30, retained #50	30	75
Passing #50, retained #80	9	32
Passing #80, retained #100	0	5
Passing #100	0	2

(d) Index of Refraction. The beads when tested by the liquid immersion method at 25°C shall show an index of refraction within the range of 1.50 to 1.65.

(e) Crushing Strength. When tested in compression at a loading rate of seventy pounds per minute, the average resistance to failure of ten beads shall be not less than the following:

20–30 mesh size............	30 pounds
30–40 mesh size............	20 pounds

(f) Chemical Stability. Beads which show any tendency toward decomposition, including surface etching, when exposed to atmospheric conditions, moisture, dilute acids or alkalies or paint film constituents, may, prior to acceptance, be required to demonstrate satisfactory reflectance behavior and maintenance under such tests as may be prescribed.

(g) Initial Reflectance. When the beads are applied at a rate of 6 pounds per gallon on binder having a wet film thickness of 15 mils, the resulting stripe, at the end of 24 hours drying, shall show a directional reflectance value of not less than 14 using the Hunter night visibility meter. The binder shall be the Virginia Department of Highways Reflectorized White Traffic Zone Paint or paint of similar pigmentation and non-volatile content.

Packing. The beads shall be furnished in units of 100 pounds packed in standard moisture proof bags.

Sample. A five pound sample of the material which the bidder proposes to furnish under this specification shall accompany each bid.

Test for Shape. Tests for roundness shall be made in accordance with Procedure A of ASTM Designation D 1155 except that paragraphs (b), (c) and (d) shall be disregarded and the following (b), (c) and (d) paragraphs substituted:

(b) Level the glass panel: then raise one end from the horizontal by the distance in inches indicated on the calibration curve in Figure 2 for the average diameter of spheres in the group.

(c) Place the sample in a suitable container for hand feeding. Start the vibrator and adjust the amplitude of vibration so that irregular particles on the upper half of the panel move slowly up the slope while the true spheres roll down. On the upper one third of the panel feed a small line of beads across the entire width of the panel so that no bunching up occurs.

(d) Observe the action of the beads on the panel closely. Allow all of the true spheres to roll into the lower receiver, then sweep into the upper receiver all of the remaining particles including those which may be rolling down the slope erratically. For the purpose of this test all particles not rolling freely down the slope are considered irregular. (Apr. 1, 1958)

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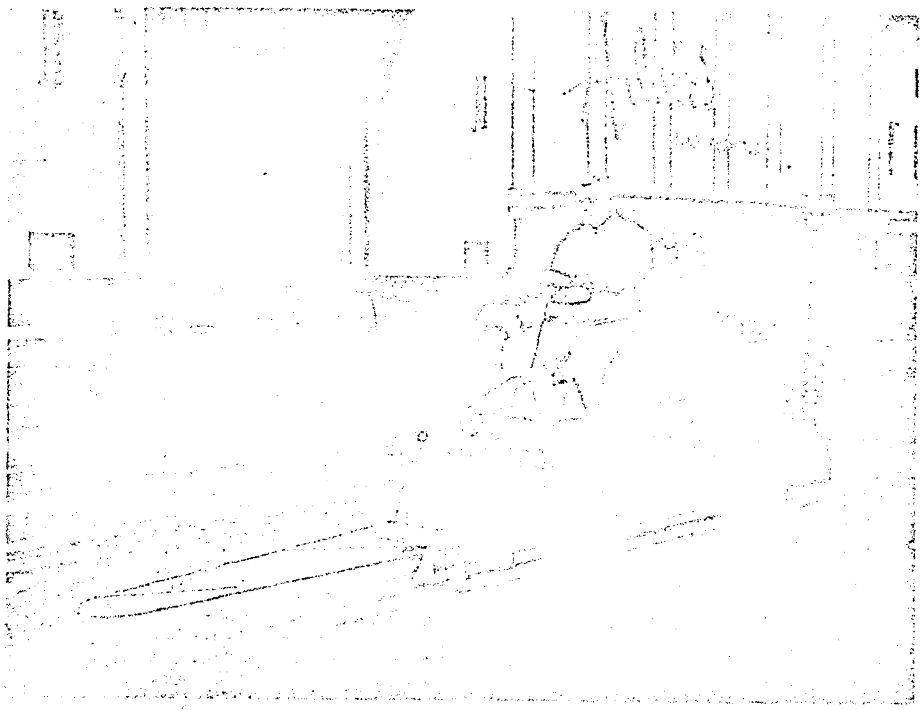
simplifies the banding operation. With it one man can quickly fasten a sign in place. The company also supplies stainless steel strapping in .020 and .032 gauges, the latter heavy enough to support traffic signals, and the necessary accessories.

Band-It Co. has stainless steel banding, brackets, buckles and the Band-It tool to be used for mounting signs, signals and control boxes.

For hanging signs and other equipment over the street, National Bracket Co. has adjustable, self-leveling brackets in four sizes.

Highway Sign Cleaner Co. has a portable sign and signal washer. Easily transported in a pickup truck, the system includes pressure pumps, hoses, brush handle assemblies and brushes for cleaning signs and signals.



Only 44 inches wide, Kelly-Creswell Mini-Liner occupies little space as it puts down double centerline. The unit carries 50 gallons of paint and has a 300-pound bead pressure system.

Pavement Markings

Pavement markings include center lines, lane lines, no-passing zone lines, turn markings, stop lines, and many others. Materials used include paint, reflectorized paint, thermoplastic compounds, metallic and plastic inserts, and various types of permanent, built-in markings which are applied during surface construction.

A suitable traffic paint must be capable of taking the hardest kind of wear under severe conditions of exposure to traffic and weather. It must also dry quickly after application. Because of their greater night visibility, reflectorized surface paints have become very popular and are used as standard materials in many locations; reflectorization is accomplished by the use of glass spheres, which are either embedded in the paint as it is being applied or actually mixed with the bulk paint.

Pavement paint-marking machines are of three general types: manually propelled; attached to or towed behind a motor vehicle; and self-propelled machines. Machines have been developed in recent years to apply simultaneously as many as three stripes, either solid or broken, and using two colors of paints, if desired. In these machines, the paint is applied by a spray gun mounted between two shields fixed to define the edges of the painted stripe. The shields may be discs, plates, or "curtains" of compressed air. Equipment necessary for mixing the paint, supplying air pressure, etc., may be mounted on the striping machine or on the vehicle.

Marking Machines

Recent evolution of highway marking equipment has been featured by the development of large truck-stripers capable of laying down as many as three lines simultaneously in one or two colors and by production of machines for the application of marking materials other than paint. Some of the larger paint applicators are now equipped with heating equipment to permit striping activities to be carried on in cold and damp weather.

M-B Corporation offers paint applicators in several sizes from small, self-propelled one-line equipment to large, truck-mounted three-line machines. They also have a narrow-chassis truck unit that is excellent for municipal and interchange work.

Wald Industries, Inc., manufactures a wide range of marking equipment. They offer the manually-operated Relecto-Liners and the truck-mounted Nite-Liners. The Wald Slim-liner is a 4-cylinder unit 48 inches wide and 145 inches long that will mark three lines in one or two colors.

Kelly-Creswell has small hand or self-propelled equipment which features the "Air Curtain". They also have a unit in the mid-range between the manually-operated and the large truck-mounted sizes. Several models will mark double lines. New is the Kelly-Creswell "Miniliner," a self-propelled centerline striper only 44 inches wide. It will put down two-color double or triple lines at speeds up to 10 mph, using electrically controlled guns. The unit has two 25-gallon tanks.

Unimasco, Inc., has a large self-propelled machine that will mark up to 6 lines simultaneously. They also have the Model 10,000 medium size vehicle striper with 3 paint guns, and five other smaller stripers. Unimasco's Model 120 is a four-wheel heavy-duty, one-man striper with all controls in the cab. Unimasco has developed a robot control for marking skip lines. Although it has a timing feature, it depends primarily on a spot light and photo-cell to control the spray gun.

Other paint stripers are made by Little Manufacturing, Inc., H. C. Sweet Co., VePed Traffic Controls, Inc., R. E. Muncey, Inc. and others.

Glass bead dispensers for mounting on stripers are made by M-B Corp., Wald Industries and C. D. Bavin Co.

Special marking equipment for application of thermo-plastic lines is available from Perma-Line Mfg. Co.

Prismo Universal Corp. has the Plasticator for cold application of its Plastix "SD" adhesive-backed marking material.

3M Company has two unique marking machines. One is designed for application of "ScotchLane", a dead soft aluminum base striping tape; the other, with LP gas torch for fusing the dry powder, "Green-Lite," to pavements. "Green-Lite" is available in liquid form, too.

Cataphote Co. has a line of six marking machines, including two truck units.

Paper board stencils for pavement markings are available from Lyle Signs, Inc.

Paints and Reflective Materials

Cataphote Corp. offers a line of reflective traffic products—Cataphote reflective pavement marking glass beads, Cataline reflective traffic paints (premix compound and drop-on combination), Catatherm thermoplastic reflective striping, Cataflex "202" reflective coating kits, Cataphote VSR Hazard Marking Kits and Cataphote reflective cold plastic tiles. "Catadots" are made as one and two-way wedges, "Dagmar" buttons and as standard dots. Cataphote also has Alert reflective liquid in several colors.

The Prismo Universal Corp. manufactures Prismo Life Line glass spheres that reflect at a wide angle of sight, Premix reflective pavement striping paint and Plastix "SD" thermoplastic, reflectorized, self-adhering permanent marking material. The Prismo Nite Line binder dries in minutes and needs no protection from light traffic. "Prismolite" is a reflective liquid for spot delineation. Prismo also offers Kristal spheres made from specially formulated "virgin" glass.

As a contract service, Prismo now offers hot-spray Plastix, which is applied at 400° by skilled workmen using unique equipment.

"Centerlite" reflectorized line-spheres and tape for temporary spheres and tape for contemporary line marking are furnished by Minnesota Mining & Mfg. Co. 3M also has "Codit" which is a reflective liquid that can be brushed, rolled or sprayed on rough to porous surfaces to make them brightly visible at night. "Scotchrock" brand reflective granules are also made by 3M. Green-Lite, a marking powder, is offered by the company. "ScotchLane" is a soft aluminum base striping tape with adhesive backing that is suitable for marking parking lots.

Perma-Line is a thermoplastic compound, extruded hot to the pavement surface where it bonds and dries in less than 15 minutes to form a semi-permanent marking. It is made by Perma-Line Mfg. Corp.

Baltimore Paint & Chemical Corp. offers Tyline traffic marking paints and Speedhide fast-drying paint. In addition, the company has Hot-Line fast-setting traffic marking compound for application by hot-striping machines.

Reflective glass beads for highway centerlines, stop signs, street name signs and plastic marking tile with embedded glass beads and glass bead dispensers are available from Flex-O-Lite Mfg. Co.

Zone-marking paints in white, black and yellow are furnished by W. R. Meadows and Zep Mfg. Corp.

Traffic paints ready to use are available from Martin-Marietta Co., The Glidden Co., Verflex Sales Corp., William Armstrong Smith Co., Gilmore & Nolan Div. of Bee Chemical Co. and Maintenance, Inc.

Parlon-Pentalyn chlorinated rubber paint additive is manufactured by Hercules Powder Co. Goodyear Tire & Rubber Co. manufactures Pliolite Solution Resins for use in traffic paint formulation.

G. H. Tennant Co. makes a traffic line eraser. Unimasco, Inc., also offers its "Erase-Rite" machine which uses 2000° heat to break down the paint elements, then shaves them.

Reflective beads are manufactured by Potters Industries, Inc.

Other Marking Materials

Metal or plastic pavement inserts are frequently used to mark crosswalks, school crossing zones, stop lines, etc. The inserts are available in various colors, sizes, and shapes. They may be inserted into the pavement and cemented in place, or cemented directly to the pavement.

Permanent center and lane lines may be cast in place as the pavement is constructed. For example, special forms may be used on a portland cement concrete pavement to form a groove in the correct position; the groove may then be filled with white concrete. Precast or extruded bars are also used.

Curbs are frequently painted to mark areas in which parking is prohibited. Objects which are adjacent to or in the traveled way and present a hazard to motorists are delineated by surface painting on the approach to the obstacle (such as a dividing island or a pier in an underpass), painting on the face of the obstacle itself (such as the headwall of a narrow culvert), and the liberal use of reflector markers, traffic signs, flashing lights, and other forms of illumination. Reflector markers are made up of single reflector buttons, groups of buttons, panels covered with reflective coatings, and similar devices. Roadside delineators, which are highly effective as an aid to night driving, are frequently provided by mounting reflector buttons on supports.

Reflective plastic pavement marking materials are offered by Prismo Safety Corp. and Cataphote Co. Thiokol Chemical Corp. has available a line-marking button and Thiokol LP epoxy adhesives that are used to bond traffic markers to both cement and bituminous concrete pavements. Martin-Marietta Co. has Lite-Lane adhesive resin lane markers.

Stimsonite reflective wedges have been designed to overcome the effect of water on the highway by offering a raised beveled surface to reflect headlight beams. Manufactured by Amerace/ESNA, they are offered in standard and snow-plowable designs. They are available in monodirectional and one or two-color bidirectional designs.

Botts-Line, Inc., makes several sizes of plastic buttons and wedges to be installed in the street. Three dimensional, beaded Botts-dots reflect light well, rain or shine.

Catadots in three forms and in white or yellow, reflectorized or non-reflectorized models are available from Cataphote Corp. Cataphote also has Alert reflective liquid.

Flexible plastic marking materials in white or yellow, reflectorized or plain, are manufactured by Holland-Suco Color Co., a subsidiary of Chemetron Corp. Called Presslabs, these materials are available in 3 to 12-in. stripes, arrows, letters, numerals or silhouette figures of varying sizes.

Magdisc pancake lights to be inserted flush with the pavement surface as a traffic guidance system are made by Strong Electric Corp.

Cones and Guards

The M-B Corporation's Line-O-Guards, made of flexible plastic, protect fresh paint lines with a spiked shape and are easy to retrieve.

Painted or reflectorized all-rubber Safe-T-Cones in 12, 18 and 28-in. sizes are available from Safe-T-Flare Corp. The apex of the cone is reinforced to hold flasher-light adapter and the base is weighted.

Safe-T-Cones and the polyvinyl Safe-T-Cones for traffic control are furnished by Radiator Specialty Co., as are a number of accessory devices.

Sleeves to slip over faded or dirty cones are obtainable from VePed Traffic Controls, Inc.

Parking Meters

The parking of automobiles on the streets or off has become a major consideration in cities and towns across the nation. While high density, high value areas have established the trend toward multi-level parking in structures, the greater number of vehicles parked each day in urban areas, at the curb or on surface lots, are at parking meters. Because of the manpower requirements of tire-chalking or other personal parking enforcement methods, time-sharing of parking locations is best provided for by meters.

Such devices are amazingly versatile. Most are capable of accepting pennies, nickels, dimes and quarters and indicating a measured time interval of appropriate duration during which the vehicle is parked legitimately. At the expiration of the period, they show a violation indicator which remains visible until another coin is inserted.

Parking meters are equally suitable for use on or off the street and, despite some experiments with meter removal, appear to have an unlimited future. They regulate parking reasonably well—and they do provide revenues to the community.

M. H. Rhodes, Inc., manufactures maximum security vault-type parking meters which have proved to be vandal resistant. Rhodes also offers meters of lighter gauge metal for use in non-problem areas. Rhodes has two-in-one meters—two timers with one vandal-resistant vault.

Rockwell Park-O-Meter automatic parking meters can be timed for any period from 6 minutes to 72 hours for any combination of coin or token. One coin slot accepts all or any coins, in any combination. Rockwell's Escrow parking meter has a memory unit and will not register any time until the full fee is paid. It is also "blind," showing only whether parking is legal or not. The Safe-Guard Park-O-Meter is vandal-proof and pilfer-proof. Rockwell also offers a manual parking meter in either traditional or vault-type vandal-proof models. New is Rockwell's pull-ring and washer rejector parking meter which probes for holes in a proffered token and refuses entry if a hole is found.

Mi-Co. parking meters are made by Hancock Industries.

Duncan Parking Meter Corp. manufactures a vandal-proof parking meter that is manually operated.

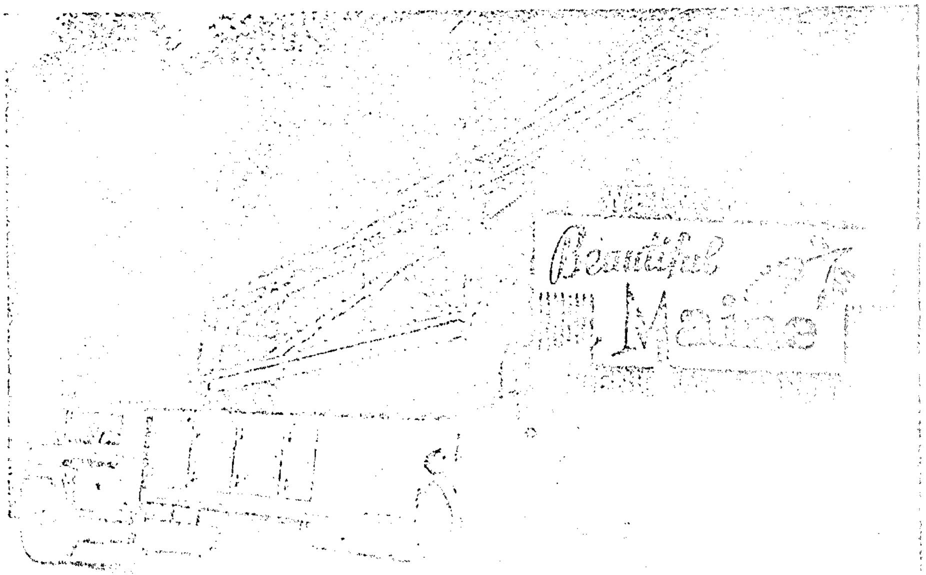
A device to test the accuracy of parking meter timers is available from ElectricEye Products Co.

Design, construction and/or operation of parking structures are services provided by consultants in the field. Their specialized services are warranted when a community or business finds that the availability of surface parking is inadequate to meet the need.

Portable Parking Structures, International, has developed a modular steel and concrete structure that is quickly erected and may be dismantled and relocated when desired.

Cincinnati Time Recorder Co. has a storage control memory unit for automatic entrance parking structures. The company also has a loop detector for parking gate operation as well as an automatic gate.

A variety of parking control equipment including ticket dispensers, controlled gates and space location controls is available from Western Industries, Inc.



Multicolored reflective sign welcomes visitors entering Pine Tree State. Sign shop personnel produced unique sign using Scotchlite sheeting, silk screens and various transparent colors.

APPENDIX B

FHWA Contact Reports

CONTACT REPORT

CONTACT BY: PHONE CALL ( ) TO BSCP (X) FROM BSCP — VISITS ( ) VISIT TO BSCP ( ) VISIT TO ______ — OTHER ( ) ______

DATE OF CONTACT: 5-6-71 GROUP: BSCP-TAG DATE OF REPORT: ______

CONTACT NAMES AND POSITIONS: Bernard Chaiken - responsible for R&D coordination on pavement striping

COMPANY OR AGENCY: FHWA/Office of Research & Development

ADDRESS: Langley, Va.

PHONE: 557-5204

BSCP PERSONNEL: H.N. Cantor

HOW CONTACT ORIGINATED (please be specific)

Recommended by Bill Williams

SUBJECT: Pavement Striping - FMOA work

REPORT:

1. Have an active program - looking towards '73 money for contracts - will emphasize 1) stripe at night in rain very heavily, 2) will also emphasize R&D to further development of rapid dry paint, 3) more permanent and economical materials.

2. Lot of Federal/State matching $ in any case
   90/10 on interstate - 1.5% for research or planning
   50/50 on non-interstate

3. Active states programs 15-20 studies at least underway, may be expanded

4. This R&D will be coordinated with NCHRP Program

(if required, use additional paper)

ACTION TO BE TAKEN:

Call Mr. Criswell (FHWA), 426-0223, Office of R&D - ask for booklet tabulation of all studies in progress as of 1 July '69, '70 Rcvd

Highway Research & Development Studies in progress as of July 1, 1969 - look for No's - 6 4 4 ---

BY: ______ DATE: ______

DISTRIBUTION: (please mark each copy)

( ) Chrono File ( ) Shilling ( ) Cantor ( ) Johnston
( ) File: ______ ( ) Weeks ( ) Wilson ( ) ICMA
( ) OTU/NASA

(4) Would be willing to participate in a NASA/ICMA/NCHRP/FHWA meeting on this problem

REPORT BY: ______

CONTACT REPORT

CONTACT BY: PHONE CALL VISITS OTHER

( ) TO BSCP ( ) VISIT TO BSCP ( ) ______

(X) FROM BSCP ( ) VISIT TO ______ ______

DATE OF CONTACT: 5-6-71 GROUP: BSCP-TAG DATE OF REPORT: ______

CONTACT NAMES AND POSITIONS: Mr. Criswell

COMPANY OR AGENCY: Federal Highway Administration, Office of R&D

ADDRESS: ______

PHONE: 426-0223

BSCP PERSONNEL: H.N. Cantor

HOW CONTACT ORIGINATED (please be specific)

Referred to him by Bernard Chajken

SUBJECT: Tabulation of R&D in progress

REPORT:

- Requested copies (3) of report entitled "Highway Research and Development Studies In Progress as of July 1, 1969".

- Copies will be sent ASAP; we are on list to receive updated version upon publication

Rcvd 5/25/71

Called again 5/24 to see why copies weren't sent; probably lost they will resend

(if required, use additional paper)

ACTION TO BE TAKEN:

BY: ______ DATE: ______

DISTRIBUTION: (please mark each copy)

( ) Chrono File ( ) Shilling ( ) Cantor ( ) Johnston

( ) File: ______ ( ) Weeks ( ) Wilson ( ) ICMA

( ) OTU/NASA

REPORT BY: ______

CONTACT BY: PHONE CALL ( ) TO BSCP (X) FROM BSCP | VISITS ( ) VISIT TO BSCP ( ) VISIT TO ________ | OTHER ( ) ________

DATE OF CONTACT: 5/24/71 GROUP: BSCP-TAG DATE OF REPORT: ________

CONTACT

NAMES AND POSITIONS: Dr. W.W. Wolman (formerly of NASA)
Chief, Traffic Safety Division Office of R&D;

COMPANY OR AGENCY: DOT/FHWA

ADDRESS: Fairbanks Highway Research Station, Va.

PHONE: 557-5221

BSCP PERSONNEL: H.N. Cantor

HOW CONTACT ORIGINATED (please be specific)

Bill Williams (NHRP) suggested I call him

SUBJECT: Re work in pavement striping

REPORT:

1) Have specialist in Materials Division working on this area, suggested calling Mr. Halstead 557-5201

2) Can dig up a list of which states are doing R&D in this area

(if required, use additional paper)

ACTION TO BE TAKEN:

I will call Mr. Halstead

BY: H. Cantor DATE: 5/25/71

DISTRIBUTION: (please mark each copy)

( ) Chrono File
( ) File: Pavement Striping
( ) Shilling
( ) Weeks
( ) Cantor
( ) Wilson
( ) Johnston
(X) ICMA
(X) NASA/OTU

REPORT BY: ________
(Signature)

CONTACT REPORT

C NTACT BY: PHONE CALL ( ) TO BSCP (X) FROM BSCP
VISITS ( ) VISIT TO BSCP ( ) VISIT TO ______
OTHER ( ) ______

.TE OF CONTACT: 5/24/71 GROUP: BSCP-TAG DATE OF REPORT: ______

C NTACT
NAMES AND POSITIONS: Mr. Halstead (will call back)
Materials Division, Office of R&D - Chaiken's boss

COMPANY OR AGENCY: DOT/FHWA
A DRESS: Fairbanks Highway Research Station
PHONE: 557-5201

BSCP PERSONNEL: H.N. Cantor

HOW CONTACT ORIGINATED (please be specific)

W.W. Wolman recommended contact

SUBJECT: Rework on pavement striping

REPORT:

It turns out that Halstead is Chaiken's boss - no contact necessary

(if required, use additional paper)

A CTION TO BE TAKEN:

None BY: ______ DATE: ______

D ISTRIBUTION: (please mark each copy)

( ) Chrono File
( ) File: Pavement Striping ✓
( ) Shilling
( ) Weeks
( ) Cantor
( ) Wilson
( ) Johnston
(X) ICMA
(X) NASA-OTU

REPORT BY: ______
(Signature)

CONTACT BY: PHONE CALL
( ) TO BSCP
(X) FROM BSCP

VISITS
( ) VISIT TO BSCP
(X) VISIT TO Conner

OTHER
( )

E OF CONTACT: 5/24/71 GROUP: BSCP-TAG DATE OF REPORT:

CONTACT
AMES AND POSITIONS: Bob Connor
Traffic Markings, Office of Traffic operations

OMPANY OR AGENCY: DOT/FHWA
ADDRESS: 7th and D Street, S.W. DOT bldg.
6-7, C-D NASSIF Bldg, Rm 3419 PHONE: 426-0411
SCP PERSONNEL: H.N. Cantor

OW CONTACT ORIGINATED (please be specific)

Bill Williams (NCHRP) recommended contact

UBJECT: Re work on pavement striping - mtg. 5/24/71; 2PM

REPORT:

1) Gave me '67 HRIS search on Highway Signs/Traffic Signals/Highway and Pavement Marking. Also gave me brief papers on "Manual on Uniform Traffic Control Devices (MUTCD)" and on "New Pavement Marking Concepts for Streets and Highways in the U.S." Finally, he gave me Street and Highway Manual '71 section on Pavement Markings.

2) His area of concern is "operations", ie application of markings, signs, etc. ~~He~~ He recommended seeing Chaiken in DOT/FHWA as"the" expert in pavement striping materials.

3) He noted that good R&D on striping is done by California, Michigan, Ohio and Minnesota. Good R&D on plastic markings is done by Kentucky, Illinois, Ohio, and California.

4) 17 states are doing R&D with federal money on evaluation of ~~leads~~ beads; report is due late in 1971 and should be of interest to cities.

5) Office of Traffic Operations is attempting to get industry involved at local level. Potters Industries Inc., 600 Industrial Road, Carlstadt, N.J. 07072, is going to

(if required, use additional paper)

ACTION TO BE TAKEN:

Try to get items referenced in paragraphs 6) and 7). ICMA should get on list for report in para. 4)

BY: H Cantor DATE: ASAP

ISTRIBUTION: (please mark each copy)

( ) Chrono File
( ) File: Pavement Striping ✓
( ) Shilling
( ) Weeks
( ) Cantor
( ) Wilson
( ) Johnston
(X) ICMA-Loren/Havlick
( ) NASA-OTU/Richards

REPORT BY:
(Signature)

5) (continued) evaluate its beads and other beads at <u>its own cost</u> on local roads in West Milford, N.J.

6) Recommended we see report entitled:
"Investigation of Points & Glass Beads Used in Traffic Delineation Markings - Phase 1" by Missouri State Highway Dept., Bureau of Public Roads, MIssouri Cooperative Highway Research Program Report #70-3, May 1970 NCHRP # 52

7) Noted that Highway Research Circular #79, April 1968, would be of interest.

CONTACT REPORT

I 'ACT BY: PHONE CALL ( ) TO BSCP (X) FROM BSCP VISITS ( ) VISIT TO BSCP ( ) VISIT TO ______ OTHER ( ) ______

TE OF CONTACT: 7/19/71 GROUP: BSCP/TAG DATE OF REPORT: 7/19/71

('TACT
IAMES AND POSITIONS: Dan Grieser

OMPANY OR AGENCY: Battelle, Columbus
I)RESS:
PHONE: 614/299-3151
SCP PERSONNEL: Todd Anuskiewicz

(7 CONTACT ORIGINATED (please be specific)
' alled to request information on highway striping research contract

UBJECT: ICMA Pavement Striping Problem

I 'ORT: I explained NASA/ICMA technology application program.

The objective of the Battelle program is to solve the wet night visibility problem in snowplow states. Their proposed solution is a molded piece of molded acrylic with the top : urface smooth and with the bottom surface containing array corner retro reflectors ,similar to car taillights). Acrylic is currently 1/8 inch thick. No study of other possible solutions was conducted.

Material is bonded to top of road or into grove in the road. It is intended to ast the life of a road (8 years).

Currently pieces are being tested in the Battelle parking lot. Subjectively paint 'ooks good when dry and plastic looks poor but the plastic looks considerably better when v et (visible up to 300 ft). Tests will be run in high density traffic in Columbus in both concrete and macadem.

Phase I is concerned with technical feasibility and not with cost. Cost might be an order of magnitude" greater than paint.

Phase II (if funded) will include additional field trials and economic considerations.

Mr. Grieser's background is in optical physics, particularly holography.

(if required, use additional paper)

CTION TO BE TAKEN:

one required

BY: ______ DATE: ______

ISTRIBUTION: (please mark each copy)

(X) Contact File
(X) File: ICMA Pavement Striping
( ) Shilling
( ) Weeks
(X) Richards
( ) Cantor
(X) Bivins
( ) Johnston
(X) Loren
( ) ______

T A N A

APPENDIX C

NCHRP Contact Reports and RFP's

CONTACT BY: PHONE CALL ( ) TO BSCP (X) FROM BSCP | VISITS ( ) VISIT TO BSCP ( ) VISIT TO ________ | OTHER ( ) ________

DATE OF CONTACT: 4/21/71 GROUP: BSCP/TAG DATE OF REPORT: ________

CONTACT
NAMES AND POSITIONS: Harry Smith/Project Engineer on Highway Research

COMPANY OR AGENCY: NAS-HRB/NCHRP
ADDRESS: 21st & Pennsylvania -5th floor
PHONE: 961-1741
BSCP PERSONNEL: H. Cantor

HOW CONTACT ORIGINATED (please be specific)
Referred to Smith by Berke/SRI

SUBJECT: Identification of MOA-sponsored R&D on pavement striping

REPORT:

Pavement Striping falls under "Traffic Control" ; should speak with Bill Williams as he knows of most federal research in this area. Proposals, review, publishing done by NCHRP (NAS Publications)

Gave me "structure" of Federal agencies involved in highway research

(if required, use additional paper)

ACTION TO BE TAKEN:
Bill Williams to call me

BY: ________ DATE: ________

DISTRIBUTION: (please mark each copy)

( ) Chrono File ( ) Shilling ( ) Cantor ( ) Johnston
( ) File: ________ ( ) Weeks ( ) Wilson (X) ICMA
(X) NASA

REPORT BY: Herbert H. Cantor
(Signature)

CONTACT BY: PHONE CALL ( ) TO BSCP (X) FROM BSCP | VISITS ( ) VISIT TO BSCP ( ) VISIT TO ______ | OTHER ( ) ______

E OF CONTACT: 4/23/71 GROUP: BSCP/TAG DATE OF REPORT: ______

CONTACT
AMES AND POSITIONS: Bill Williams, Project Engineer

OMPANY OR AGENCY: NCHRP/HRB/NAS
ADDRESS: Joseph Henry Building
PHONE: 961-1741
SCP PERSONNEL: Herb Cantor

OW CONTACT ORIGINATED (please be specific)
Referred to Mr. Williams by Harry Smith

UBJECT: Pavement Striping-MOA- R&D search
REPORT:
1) Has been monitor for pavement striping R&D since 1964, had talked with MacIntyre of TU in 1965.
2) Will be project manage on new $200 K contract for research on Innovative Pavement Stripings (has 10 proposals in response to RFP)
3 Pavement Stripings a gigantic business market, very competitive
4, Has $100K project underway at Penn State re glass beads
5) Recommended using the Highway Research Information System and Transportation Research Activities Information Systems under the aegis of Dr. Paul Irick/Highway Research Board to locate Federal R&D in this area ✓
6) Recommends speaking to Bernard Charken, Federal Highway Administration, Office of R&D, Langley, Virginia as he knows more about pavement striping than anyone else-key man! Phone No. 557-5204 (Langley, Virginia) ✓
7) Recommends speaking to Harvey Miller&/or Emil York, Organic Coatings Research, Materials Research Support Division, Department of Army-U.S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Virginia ✓

(if required, use additional paper)

ACTION TO BE TAKEN:
1 Williams to send me copies of their latest RFPs, information on the NCHRP Program RCVD
2) Cantor to inform OTU, ICMA of possibility of direct interaction with Williams ✓ done

BY: 1) Williams 2) Cantor DATE: ______

DISTRIBUTION: (please mark each copy)

( ) Chrono File | ( ) Shilling | ( ) Cantor | ( ) Johnston
( ) File: ______ | ( ) Weeks | ( ) Wilson | (X) ICMA
(X) NASA

REPORT BY: Herbert H. Cantor
(Signature)

CONTACT BY: PHONE CALL — ( ) TO BSCP; (X) FROM BSCP — VISITS — ( ) VISIT TO BSCP; ( ) VISIT TO ______ — OTHER ( ) ______

E OF CONTACT: 4/23/71-busy 4/26/71 GROUP: BSCP/TAG DATE OF REPORT: ______

CONTACT

AMES AND POSITIONS: Art Mobley [961-1782]

OMPANY OR AGENCY: NAS/HRB-Highway Research Information System (HRIS)

ADDRESS: Joseph Henry Building

PHONE: 961-1782

SCP PERSONNEL: Herb Cantor

HOW CONTACT ORIGINATED (please be specific)

eferred to him by Bill Williams, Harry Smith

JBJECT: Pavement Striping MOA-R&D

REPORT: 1) Highway Research Information System resumes of ongoing work, past publications & work: publications-current. RIP-current to March 1971.

2 Charge for service/literature search-$200 base charge, +$1/page for print out; NASA could request search from Federal Highway Administration, Federal Highway Administration would tell em to run it; expect ~$250 cost, including abstracts.

3 Do not have hard copy on file; copy available from National Technical Information System

4) Includes unclassified DOD work

5) Would take at most 2 weeks

6 Last search on Pavement Striping run 1 1/2 years ago

7. Highway Research Board library can do Search-Hard copy; Files can be browsed, they have indexes

(if required, use additional paper)

CTION TO BE TAKEN:

y Bivins to contact Federal Highway Administration: Mr. Gordon Gronberg (Code 118, ext.60224) to request search

1P

BY: ASAP DATE: ______

ISTRIBUTION: (please mark each copy)

( ) Chrono File	( ) Shilling	( ) Cantor	( ) Johnston
( ) File: ______	( ) Weeks	( ) Wilson	(X) ICMA
			(X) NASA

REPORT BY: Herbert M. Cantor

(Signature)

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Highway Research Board
National Academy of Sciences—National Research Council

1964-65

Project Statement

Research Project Title:

Nighttime Use of Highway Pavement Delineation Materials

Research Problem Statement:

Pavement marking materials in common use lose their effectiveness to a marked degree during periods of darkness in adverse weather. Development of better performing materials and methods for their use, or other means for more effective delineation of traffic lanes for wet pavement conditions are needed. Ease of driving and highway safety will be enhanced when effectiveness of pavement delineation under wet conditions approaches the effectiveness provided under normal conditions.

Objectives:

1. To measure the degree of effectiveness of pavement marking materials on highway tangents for specified nighttime wet and dry conditions. Factors relating to the degree of effectiveness may include, but are not limited to, photometric properties of delineation material and pavement, relative contrast between delineation materials and pavement, state of visual adaptation, color properties, marking pattern, and visual range (viewing distance when driving).

The research proposal should specify the wet and dry conditions to be studied. The study should be made for surfaces that are typical of worn portland cement and bituminous concrete type pavements. Two-lane highway tangents having a minimum of ambient light (and no opposing traffic) shall be considered to be the governing case. Several conditions of wetness simulating those actually encountered on highways shall be employed. The illumination source shall be equivalent to low beam headlights of an average vehicle.

2. To set forth the causes for differences in effectiveness as found in the research.

3. To suggest ways and means of obtaining maximum effectiveness of pavement marking materials under nighttime wet and dry conditions (innovations leading to increased effectiveness should be explored).

Since the recommendations should have practical application, any major findings of promise should be field tested under real life conditions.

Funds Available: $50,000

Completion Time: 18 Months

(OVER)

Deadline for Filing Proposal: August 3, 1964

Authorization to Begin Work: Notice to proceed on this contract cannot be expected until February-April, 1965.

Mail Proposal to:

Mr. M. Earl Campbell
Program Engineer
Highway Research Board
2101 Constitution Avenue, N. W.
Washington, D. C. 20418

6-2-64
mh

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Highway Research Board
National Research Council
National Academy of Sciences--National Academy of Engineering

FY '71

Project Statement

Project No.: 5-5 Continued

Research Project Title: Development of Optimum Specifications for Glass Beads in Pavement Markings

Research Problem Statement:

Effective utilization of glass beads used for reflectorization of pavement marking materials is dependent on a number of variables that are not fully understood or defined. As a result, various bead gradations and compositions, thicknesses and composition of the binder, bead surface treatments, rates of application, and so forth, are used today. A better understanding of the principles surrounding performance of glass beads in traffic paint markings is necessary if delineation techniques are to be improved and maximum benefits are to be derived from use of glass beads.

Objectives:

(1) Review and analyze world-wide research and practices involving the use and manufacture of traffic marking beads.

(2) Identify those variables that markedly influence the effective utilization of glass beads in pavement markings. Evaluate these variables by laboratory and field tests as required in order to rate them in terms of their influence on the effectiveness and serviceability of delineation under actual traffic conditions. Field tests shall include measurements of wet-nighttime reflectivity.

(3) Determine the capability and economics of producing glass beads of specified gradation, composition, shape, flow properties, color, etc.

(4) Develop practical specifications and criteria for the selection and use of beads for reflectorizing traffic paint markings.

(5) Evaluate for one or more states the probable benefits that would accrue should the proposed specifications be adopted in place of current specifications.

Reports:

An interim report of substantive nature is due at the end of one-half of the research period. The draft final report is due at the end of the research.

Funds Available: $100,000

Contract Time: Up to 21 months for research (An additional 3 months will be provided for review and revision of the draft final report.)

Authorization to Begin Work: Final award of the contract for this research is expected to be made in the period January 1971 - February 1971.

Submit Twenty-Five (25) Copies of Proposal to:

K. W. Henderson, Jr.
Program Director, NCHRP
Highway Research Board
2101 Constitution Avenue, N. W.
Washington, D. C. 20418

PROPOSAL DEADLINE: Proposals are due not later than 4:00 p.m., November 16, 1970.

Note 1. "The National Academy of Sciences, in accordance with the provisions of Title VI of the Civil Rights Act of 1964 (78 Stat. 252) and the Regulations of the Department of Commerce (15 C.F.R., Part 8), issued pursuant to such Act, hereby notifies all parties that it will affirmatively insure that the contract entered into pursuant to this announcement will be awarded without discrimination on the ground of race, color, or national origin."

Note 2. The essential features desired in a proposal for research are stated in the National Cooperative Highway Research Program brochure entitled "General Information for Administration and Contracting." Particular attention should be given to the information on pages 8 and 9 pertaining to the Principals and Research Plan. Proposals will not be accepted if the research plan does not include a section captioned, "Applicability of Results to Highway Practice." This section is to convey clearly the specifics of how the anticipated results could be used to improve highway practices and the manner in which the desired results would be reported.

All pertinent information is required to be bound in a single-volume proposal. For example, some agencies include the proposed budget in the letter of transmittal, or as a separate volume. Neither is acceptable; the letter and the budget are to be bound in the proposal. Furthermore, the cover page of the proposal should clearly set forth the NCHRP project number, and each of the 25 copies should be numbered from 1 through 25 prominently in the upper right-hand corner.

Note 3. Mr. William L. Williams will be the Projects Engineer having responsibility for surveillance of this project and can be reached at (202)961-1741 to answer inquiries.

Note 4. Although our mailing address is as stated above, you should be aware that our offices are located on the 5th floor (Room 528) of the (George Washington University) Joseph Henry Building at 2100 Pennsylvania Avenue, N. W., in the event that you might have occasion to visit or hand-carry proposals on their due date.

Note 5. All proposals become the property of the National Cooperative Highway Research Program, and final disposition will be made according to the policies thereof.

Note 6. Requests for the current NCHRP brochure (blue-covered document) should be addressed to:

L. M. MacGregor
Administrative Engineer, NCHRP
Highway Research Board
2101 Constitution Avenue, N. W.
Washington, D. C. 20418

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Highway Research Board
National Academy of Sciences--National Research Council

FY '72

Project Statement

Project No.: 5-5B

Research Project Title:

Pavement Marking Systems for Improved Wet-Night Visibility Where Snowplowing is Prevalent

General Problem Area:

Illumination and Visibility

Research Problem Statement:

Conventional reflectorized pavement marking systems in common use lose their effectiveness markedly during periods of darkness in rainy weather. Raised reflectorized markers are quite effective under such circumstances and are in use where exposure to snowplows is not a factor. However, such markers may be quickly dislodged or destroyed in a large part of the U. S. where snowplowing is common during the winter months. Past and current research to achieve wet-night pavement delineation compatible with snowplowing operations includes: Low profile-large bead marking systems; combined longitudinal grooving and stripping; rubber-tipped snowplow blades compatible with raised marking systems; so-called "snowplowable" raised markers; thickly-applied corrugated thermoplastic stripes; as well as various U. S. and foreign wet-weather pavement delineation devices and concepts. To a large extent, none of these developments and concepts has been fully accepted or utilized because of restricted applicability, limitations in performance, cost, or limited degree of development and practicality. Thus, there remains a continuing need for additional research to explore further the development of alternative, innovative, and practical pavement marking systems that are economically feasible, effective under wet-weather conditions, and, at the same time, compatible with snowplowing operations.

Objectives:

1. Development of one or more innovative concepts for pavement marking system(s) that are practical, economical and effective under nighttime wet pavement conditions, and compatible with snowplowing. The marking system(s) shall be effective during rainfall with a minimum of approximately 0.030 inch of water on the pavement surface. The system(s) shall also be practical under high-speed snowplowing with steel blades in contact with the pavement surface. The system(s) may supplement existing marking systems or be a replacement for them.

2. Laboratory and controlled field evaluation of the system(s) developed in Objective 1 and demonstration of its practical and economic feasibility. The field evaluation must include some evaluation on public highways over two winters.

   Note: It is intended that the proposal shall detail to all possible extent the specifics of the innovative concepts that the proposer will consider for development in Objective 1. Among other things, the proposals will be evaluated on the basis of the innovativeness, feasibility, and practicability of the proposed concepts.

Funds Available: $200,000

Contract Time: Up to 33 months (an additional 3 months will be provided for review and revision of the final report).

Authorization to Begin Work: Final award of the contract for this research is expected to be made in the period August — September 1971.

Submit Twenty-Five (25) Copies of Proposal to:

K. W. Henderson, Jr.
Program Director, NCHRP
Highway Research Board
2101 Constitution Avenue, N.W.
Washington, D. C. 20418

PROPOSAL DEADLINE: Proposals are due not later than 4:00 p.m., April 19, 1971. This is a firm deadline, and extensions simply are not granted. In order to be considered, proposals must have been received in the offices of the NCHRP not later than the deadline shown. The NCHRP does not recognize the U.S. Mail, Railway Express Agency, Air Express, or any other organization, as its agent for purposes of accepting proposals. All proposals arriving after the deadline shown on the project statement will be rejected.

Note 1. "The National Academy of Sciences, in accordance with the provisions of Title VI of the Civil Rights Act of 1964 (78 Stat. 52 and the Regulations of the Department of Commerce (15 C.F.R., Part 8), issued pursuant to such Act, hereby notifies all parties that it will affirmatively insure that the contract entered into pursuant to this announcement will be awarded without discrimination on the ground of race, color, or national origin."

Note 2. The essential features required in a proposal for research are detailed in a new (January 1971) National Cooperative Highway Research Program brochure entitled "Information and Instructions for Preparing Proposals." Proposals must be prepared according to this document to be acceptable. For example, they will not be accepted if the research plan does not include a section captioned, "Applicability of Results to Highway Practice." This section is to convey clearly the specifics of how the anticipated results could be used to improve highway practices and the manner in which the desired results would be reported; e.g., mathematical models, design techniques, field or laboratory test procedures, models for changes in AASHO, FHWA, or standard highway specifications. If the nature of a project is such that it is known initially that the results will not be applicable to immediate implementation into practice, the research plan must include recommendations as to the additional work visualized necessary to reach the implementation stage.

All pertinent information must be bound in the proposal so as to prevent its becoming separated, and a single volume is required. For example, some agencies include the proposed budget in the letter of transmittal, or as a separate volume. Neither is acceptable; the letter and the budget should be bound in the proposal. Furthermore, the cover page of the proposal should clearly set forth the NCHRP project number, and each of the 25 copies should be numbered from 1 through 25 prominently in the upper right-hand corner.

Note 3. Mr. William L. Williams will be the Projects Engineer having responsibility for surveillance of this project. He can be reached at (202) 961-1741 to answer inquiries.

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Note 5. All proposals become the property of the National Cooperative Highway Research Program, and final disposition will be made according to the policies thereof.

Requests for the new brochure, "Information and Instructions for Preparing Proposals," should be addressed to:

L. M. MacGregor
Administrative Engineer, NCHRP
Highway Research Board
2101 Constitution Avenue, N.W.
Washington, D. C. 20418

APPENDIX D

NCHRP Reports Relevant to Pavement Markings

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT 45

DEVELOPMENT OF IMPROVED PAVEMENT MARKING MATERIALS

LABORATORY PHASE

There is a more recent report by Dale; NASA was unable to help with the second contract road with glass spheres

JOHN M. DALE
SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO, TEXAS

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS IN COOPERATION WITH THE BUREAU OF PUBLIC ROADS

— now doing work on glass beads, Penn State University

SUBJECT CLASSIFICATION:
GENERAL MATERIALS
MAINTENANCE, GENERAL
HIGHWAY SAFETY
TRAFFIC CONTROL AND OPERATIONS

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING
1967

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Bureau of Public Roads, United States Department of Transportation.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

This report is one of a series of reports issued from a continuing research program conducted under a three-way agreement entered into in June 1962 by and among the National Academy of Sciences-National Research Council, the American Association of State Highway Officials, and the U. S. Bureau of Public Roads. Individual fiscal agreements are executed annually by the Academy-Research Council, the Bureau of Public Roads, and participating state highway departments, members of the American Association of State Highway Officials.

This report was prepared by the contracting research agency. It has been reviewed by the appropriate Advisory Panel for clarity, documentation, and fulfillment of the contract. It has been accepted by the Highway Research Board and published in the interest of an effectual dissemination of findings and their application in the formulation of policies, procedures, and practices in the subject problem area.

NCHRP Project 5-5 FY '65
NAS-NRC Publication 1549
Library of Congress Catalog Card Number: 67-62902

FOREWORD

By Staff

Highway Research Board

This report will be of special interest to traffic engineers, materials engineers, and other public officials responsible for the design of highway pavement marking systems having improved safety features. This laboratory and field investigation presents an evaluation of pavement marking materials currently in use and a discussion of their shortcomings. Practical recommendations are made for the improved design of economical markings that would be more visible than conventional markings, both day and night. Special emphasis is given to the visibility of markings at night during periods of severe rainfall and a new, unique, low-cost, experimental marking has been developed and tested on a public highway. The newly conceived marker's ability to be visible at night when wet was judged excellent; furthermore, the low-profile marker is not likely to be damaged by snowplows. Implementation of the concepts presented should provide a more visible pavement marking that will increase the safety aspects of the highway, particularly on rainy nights.

This report stems from NCHRP Project 5-5 entitled "Nighttime Use of Highway Pavement Delineation Materials." Only the findings of the initial laboratory phase are presented herein. The results of the field testing phase will be presented in a future NCHRP report.

Present reflectorized highway paint markings lose their effectiveness to a marked degree during periods of darkness in adverse weather. However, during these periods the need for guidance is most critical and ease of driving and highway safety will be improved when the effectiveness of pavement delineation under adverse weather conditions approaches the effectiveness provided under normal conditions. With these thoughts in mind the research was initiated to seek ways of improving delineation of roadways under wet and dry conditions by improving techniques utilizing existing materials or by developing new materials and techniques.

Southwest Research Institute, in this thorough and well-documented effort, initiated a field study of the performance characteristics of conventional marking materials. Following this, their researchers conducted studies of the physical nature of reflective materials, with particular emphasis on performance characteristics under various types of water films. Based on the results of the laboratory and field tests a new pavement marking was designed and tested with very encouraging results. A systematic approach for the design of a pavement marking system has been developed wherein one qualifies the surface to be marked, determines the water film thickness to be encountered, and then selects one of the several marking systems that will perform under the imposed conditions.

The research points out that where pavement markings fail by mechanisms other than loss of their upper surface, a glass bead system having a uniform size gradation matched to the binder thickness should be used. Experiments have been conducted to determine the effectiveness of silicone-treated glass beads and the optimum depth of imbedment for glass beads to obtain maximum retroreflection. The feasibility of applying a surface coating of small beads to a carrier (pea-gravel) was investigated as a way to obtain a large-diameter reflecting material that would protrude through submerging water films.

After considering the factors that influence the performance of marking materials the researchers developed a new system of pavement markings that could be applied like paint but performs like raised reflectorized markers. In this system $\frac{1}{4}$-in. diameter glass beads are embedded in a pigmented epoxy binder.

The second phase of the research is under way to further develop and field test the new marking system that emerged from the initial laboratory research. The objective of the additional research is to optimize the application equipment, materials, and techniques necessary to demonstrate the practical feasibility of the new marking system.

CONTENTS

FIGURES

TABLES

ACKNOWLEDGMENTS

The study reported herein was conducted in the Process and Product Development Section, Department of Chemistry and Chemical Engineering, Southwest Research Institute, with John M. Dale as Principal Investigator. Other Institute personnel associated with the project include Allen C. Ludwig, Elgin O. Ott, and William T. Clayton.

The author is indebted to the Texas State Highway Department, the Los Angeles County Road Department, and J. E. Bauer Company, and gratefully acknowledges sample quantities of reflective materials contributed by the Cataphote Corporation; Corning Glass Works; Elastic Stop Nut Corporation; Ferro Corporation; Flex-O-Lite Manufacturing Corporation; Marbon Chemical Division of Borg-Warner Corporation; Minnesota Mining and Manufacturing Company; Potter Brothers Glass Company; Prismo Safety Corporation; Reflecting Roadstuds, Ltd.; Rupert Manufacturing Company; and Traffic Standard, Inc.

DEVELOPMENT OF IMPROVED PAVEMENT MARKING MATERIALS

LABORATORY PHASE

SUMMARY

The information contained in this report will enable agencies responsible for highway pavement delineation to better understand the many variables that influence the performance of marking systems both in the day and night and particularly at night during periods of precipitation when many of the currently used marking systems become inoperative.

Beyond explaining how various marking systems work and their advantages and limitations, a systematic approach to decision making with regard to the marking of pavements has been developed, and a form is presented wherein engineers can select systems that will give day and night, dry and wet visibility at the lowest cost per mile per day of useful life. To do this, the engineer obtains a profile of the surface to be marked, qualifies the water-film thicknesses to be encountered during periods of precipitation, and then selects the marking system that will perform under the imposed conditions. Information in this report should be of use to engineers in designing new and improved systems. As an example, one such system is cited in this report and is documented through its initial field evaluations. The concept involves incorporating into one system the ability to be applied like paint and yet perform like raised, reflectorized markers as a means of combating the visibility problem of markings during periods of darkness and precipitation.

It is suggested that further research be conducted to investigate the development of heavier and more durable marking materials. Considerable attention should be directed to the study of raised markers in terms of their present and future use, both separately and in conjunction with surface-film markings and their relation to snow removal operations from the standpoint of determining if the marking system should be designed to accommodate the snow removal equipment or if the snow removal equipment should be designed to accommodate the marking system or if there is a compromise solution.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

Commonly used pavement marking materials lose their effectiveness to a marked degree during periods of darkness in adverse weather. A driver's need for guidance is most critical during these periods, and driving ease and highway safety will be enhanced when the effectiveness of pavement delineation under adverse weather conditions approaches the effectiveness provided under normal conditions. The objective of this program was to study ways of improving delineation of roadways under wet and dry conditions by either improving techniques that use existing materials or developing new materials and techniques.

Pavement markings are but one facet of a complex set of interrelated factors that influence the visual problems of the motorist at night. Illumination, contrast, placement, size of object, shape, brightness, and time of exposure are but a few of these factors. If one could redesign the automobiles, changing the location of the driver and headlights, convert to a polarized light system, redesign the roadway and include self-illuminated markings plus various other changes, some rather dramatic visual improvements would result. However, such a long-range approach would do little to combat today's problems. In spite of certain limitations, the present system of marking roadways using surface markings that have been reflectorized has the advantage, under favorable conditions, of conveying a steady stream of uninterrupted visual information or warnings to the driver without diverting his attention from the roadway.

In the modern automobile the headlights, which may be only 26 in. above the road surface, provide the source of illumination. This illumination diminishes in intensity as the distance from the source increases, so that maximum safe operating speeds on low and high beams are considered to be approximately 30 and 55 mph, respectively, with perception distances for unmarked dark objects considered to be of the order of approximately 100 and 350 ft, respectively. Assuming a level pavement, a ray of light from a typical automobile strikes the pavement at an angle of 1 deg 14 min with the horizontal 100 ft in advance of the vehicle. This angle becomes progressively smaller and finally narrows to 0 deg 21 min at a distance of 350 ft. The light striking the surface of the road ahead of the vehicle is largely reflected forward or absorbed by the road surface itself. For the light striking the pavement marking to be directed back to the driver's eyes and present a clearly visible image, an optical focusing device is required. Most commonly used are small glass beads or spheres imbedded in the pavement marking material which focus and return the light to the vicinity of its source with varying efficiency, depending on a number of variables, including refractive index, true spherical shape, imperfections, and other variations in the beads themselves. Not all of the light striking a given bead will be reflected off its surface. That light which penetrates the bead and is refracted, focused, and redirected back to the driver suffers losses from absorption and scatter. Depending upon the road contour and during ideal dry weather conditions, pavement marking materials with glass beads properly applied can be very easily distinguished at night with high-beam headlights well beyond 350 ft, where there is no opposing traffic. The glare from the headlights of approaching vehicles and other light sources can very often be so intense as to limit a driver's ability to distinguish reflectorized markings for short periods to those directly in front of his vehicle.

During periods of adverse weather, the small glass beads often become submerged under a covering layer of water. Light from the drivers' headlights is largely reflected off the water surface and lost, and the small amount of light that penetrates the water suffers further losses to reflection, refraction, absorption, and scatter in its passage in and out through these various media. Thus, the retroreflective capabilities of currently used highway markings are generally lost during adverse weather, which greatly impairs the safety of the motorist during the period when his need for visual assistance is greatest.

RESEARCH APPROACH

The approach used to fulfill the study goals was to gather information with regard to how presently used marking systems perform in their environment and, within this framework, to determine techniques for improving present systems and, hopefully, to conceive other improved systems. It is pointed out that the emphasis in this program was placed on measurements and observations in the field under actual and simulated conditions rather than on the theoretical treatment of ideal systems.

Data Collection

In obtaining the information presented in this study, an extensive effort was made to get from manufacturers the best of currently available materials used for marking and reflectorizing highway pavements. Excellent response was received from the principal manufacturers as listed in the Acknowledgments. Their materials were placed in field road tests and evaluated, not from the standpoint of comparing one manufacturer's product with another but of observing the basic performance advantages and limitations of the different systems. Concurrent with the field evaluations of available marking systems, other field and laboratory studies were undertaken to more accurately define how glass beads function as retroreflective elements in highway marking materials and to qualify water-film thicknesses as encountered on roadways during periods of precipitation. This work is presented and discussed in Chapter Two.

Interpretation

The analysis of the work was undertaken by comparing data on water-film thicknesses obtained both in the laboratory and in the field with data pertaining to the performance characteristics of reflecting materials as determined in the laboratory and, finally, comparing all of these data with those pertaining to performance characteristics of present systems as observed in the field. It was then possible to make observations with regard to the basic advantages and limitations of present systems as well as to suggest methods of improving present systems. Results of this work are presented and discussed in Chapter Three.

Application

It was hopefully anticipated that during the course of this project some concept of a new and potentially improved system would evolve. Such a system did emerge, was taken into preliminary field evaluations, and appears to be an attractive concept within the limits that could be pursued in the final phase of this program. This work is presented and discussed in Chapter Four.

CHAPTER TWO

RESEARCH FINDINGS

This chapter is divided into three parts and contains the principal findings of the study. The first part covers field evaluations of conventional marking materials, describes how the field evaluations were conducted, and discusses the performance of conventional materials. The second part is devoted to the subject of precipitation and discusses its forms, characteristics, and the measurement of water-film depths on road surfaces. In the third part, the physical and retroreflective characteristics of glass beads are discussed.

FIELD EVALUATIONS OF CONVENTIONAL MARKING MATERIALS

Field evaluations of conventional materials were undertaken not to evaluate or rate the effectiveness of various manufacturers' products, but rather to examine the latest available commercial materials with regard to their general effectiveness and to help define in more specific terms the principal problem area of loss of visibility of marking materials during periods of precipitation.

Test Equipment

Paint stripes and reflective materials were applied with a Kelly-Creswell Model B-3-P, all-purpose striping machine. Special attention was given to handling the reflective materials. In addition to the use of a conventional gravity-feed, bead-dispensing apparatus, a chain-driven, proportioning-type bead dispenser was installed to provide precise control of bead application rates.

A water-spray device consisting of five nozzles was designed and fabricated to simulate rainfall over the entire length of a 15-ft painted segment of a broken line, commonly used as a standard for center and lane lines. The spray device combined the better features of similar devices used by General Motors Corporation and the U.S. Corps of Engineers, Fort Belvoir, Va., to simulate wet weather conditions. Nozzle Model Numbers 1/3GG2, 1/8GG3, 1/8GG3.5, 1/8G5, and 1/2G25 were purchased from the Spraying Systems Company, Bellwood, Ill. These nozzles are the full-cone type and provide a spray with an even distribution pattern. Flow rates were controlled by selection of nozzle size and water pressure. Rates of precipitation were further checked by placing conventional rain gauges at various points within the fall pattern.

In view of the dramatic difference between the wet and dry retroreflective capabilities of conventional marking materials and the lack of an industrially accepted measuring device, diversion of project funds to develop an optical instrument was not considered appropriate. After reviewing manufacturers' reports and car registration data, a 1965 Chevrolet was selected as the typical new car to be simulated. Thus, 1965 Chevrolet headlamps were installed on a plywood dummy, with careful attention given to dimensional locations on the dummy. A dimmer switch was installed for evaluations on both low and high beam, and an ammeter was installed in the circuit as a means of monitoring output. The power source was a 12-v battery which was kept fully charged by a portable d.c. generator. After installation, the headlamps were aligned with a Weaver photoscope headlight tester. Figure 1 is a photograph of these three pieces of equipment.

Materials Acquisition and Field Application

At the beginning of the project, letters were sent to manufacturers of reflective materials advising them of Southwest Research Institute's having been awarded the subject contract and of its interest in obtaining samples of their materials for study. Excellent and generous response was received from these inquiries, and a large number of samples were obtained representing, after elimination of duplicating products, some 9 different types of glass beads and some 18 different types of raised markers of both the reflectorized and unreflectorized type. These materials were taken to the test site and applied in accordance with the manufacturers' recommendations when received and otherwise by the best techniques available. The site selected for initial screening studies was on Southwest Research Institute grounds at a remote area with little traffic and free of foreign light sources at night. The pavement surface was a new, well-contoured, smooth asphaltic concrete, free of cracks, holes, and patches.

The paint was applied in stripes 4 in. wide and 15 ft long and set on 1-ft centers. The paint stripes were applied in groups of five, each group having a wet film thickness of 10, 15, 20, 25, and 30 mils, respectively. All groups received the same type of beads, which were dropped on at a rate of 6 lb per gal of paint, based on an assumed wet film thickness of 15 mils. One group of stripes was left unbeaded to serve as a control. The paint stripes and beads were applied with the striping machine. After application, the stripes were kept free of all traffic until they were completely dry. Four of each of the different types of raised markers were applied as a unit, equally spaced over a 15-ft length.

Evaluation Ratings of Marking Materials

ON SPRING APPLICATION

In the various model codes for evaluating highway marking materials, the three basic performance factors of appearance, reflectance, and durability are evaluated. In this initial phase of the study, attention was concerned

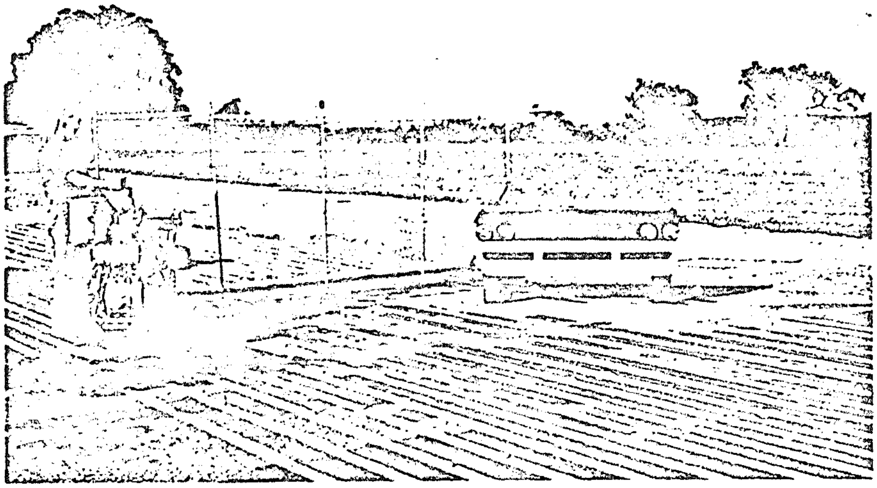


Figure 1. Equipment used in field evaluations of pavement marking materials.

primarily with reflectance, particularly during adverse weather. The materials were applied during the week beginning May 24, 1965, and evaluated in daylight and darkness under the wet and dry conditions. Night observations were made from a distance of 150 ft, with the lighting apparatus turned to either low or high with the beams focused longitudinally on the stripes, just as a driver would encounter a broken center or lane line. Selected observers rated reflectance visually with a rating scale from 0 to 10, with 0 indicating nonperformance and 10 indicating best performance.

Of the 65 paint stripes evaluated at night, all except 5 of the control stripes, which were unbeaded, and 3 stripes with special bead-coated granules were readily visible when dry. Visibility of the stripes dry improved as a direct function of the refractive index of the glass beads, those having a refractive index of 1.9 being considerably more reflective than those with a refractive index of 1.5. Under wet conditions at night, 60 of the 65 stripes were obliterated when subjected to a simulated rainfall of 4 in. per hr. Of the five stripes that reflected under simulated rainfall, two were of a tape-striping material and the other three had received an application of special bead-coated granules that showed poor reflectance when dry. The visibility of the silicone-treated and untreated beads was equally destroyed under the spray at high precipitation rates. When the surfaces of the two tape striping materials that performed well when wet were examined closely, it was noted that water beaded on their surfaces rather than flowed out over the stripe in a continuous film; therefore, many of their retroreflective elements were exposed and active. The three stripes that were coated with special bead-coated granules, which showed poor reflectance when dry but good reflectance when wet, did not reflect the color of the binder material but gave a gold-like color impression.

Under dry nighttime conditions, 10 of the 18 stripes employing raised markers were rated at 4 and above. The eight with ratings lower than 4 were unreflectorized markers. Under wet conditions, 8 of the 10 raised, reflectorized markers visible under dry conditions were rated at 4 and above. Thus, two of the raised, reflectorized marker types received a rating of 9 when dry and 9 when wet and were indeed as easily distinguishable when subjected to the water spray as when dry.

ON FALL INSPECTION

The test materials were allowed to weather over the summer, and, on September 27, 1965, after a 4-month exposure period, reevaluation of the markings was made. The 65 paint stripes in the dry condition had essentially the same ratings as they did in the spring. As pointed out previously, there was a minimum of traffic over the test site during the test period. In the wet condition, all of the stripes, except the two formed of tape-striping materials, were obliterated. Although these two stripes had lost their ability to bead water, their surfaces were sufficiently elevated so that many of their reflective elements were never submerged and remained active. Figure 2 is a photograph taken at night during the fall inspection of the test site in the dry condition. The brightest and most easily distinguishable stripes at the test site were a series of five located in the third row on the left side. On these stripes glass beads with a refractive index of 1.9 were used. Immediately behind these five stripes are five control stripes of paint, which had no bead treatment and thus were very difficult to distinguish. In Figure 3, the site is viewed with the water-spray rig mounted over these five brightest stripes; at a simulated rainfall rate of approximately 4 in. per hr, they can barely be distinguished. The raised markers had essentially the same ratings as they did in the spring. In Figure 4, the site is viewed with the water-spray rig mounted over a series of raised, reflectorized markers located to the extreme rear of the site; at a simulated rainfall rate of approximately 4 in. per

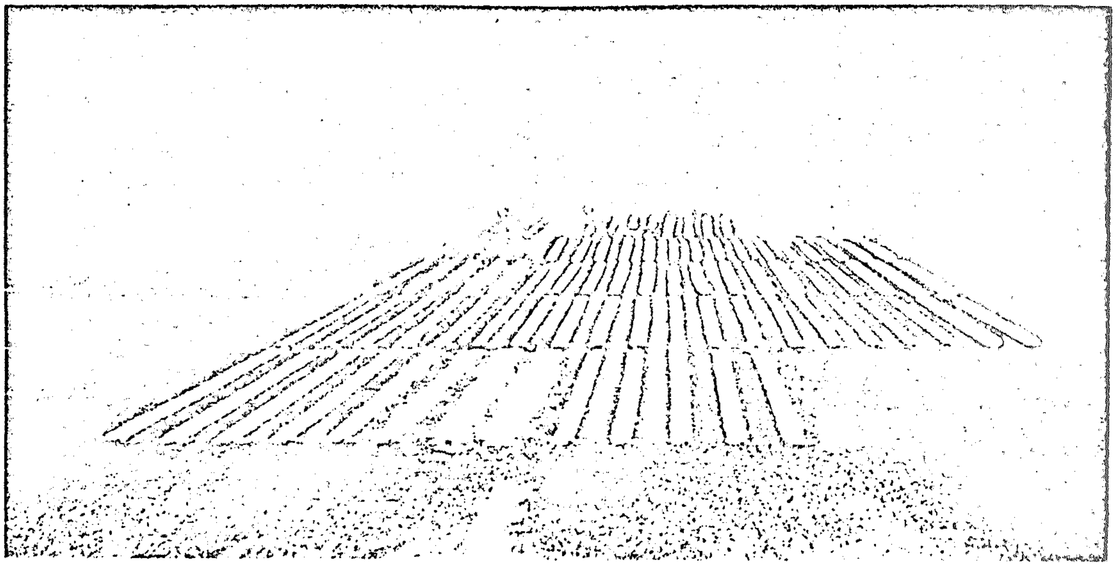


Figure 2. Test site at night, dry.

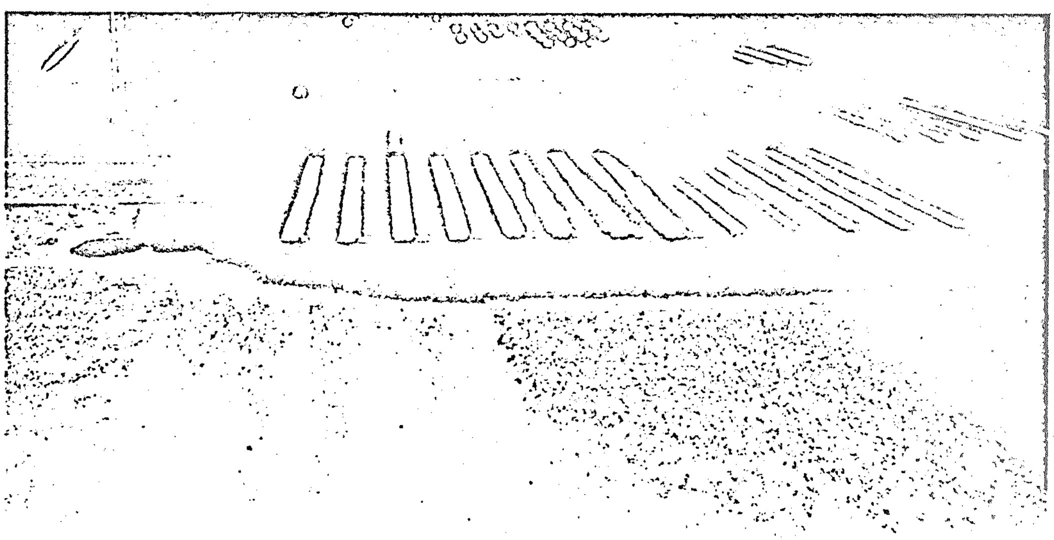


Figure 3. Water spray over brightest beaded stripes at test site.

hr, they are very distinguishable. It is interesting to note that the reflectorized paint stripes in the foreground, which are no longer being sprayed, are again becoming reflective.

PRECIPITATION—ITS FORMS AND CHARACTERISTICS

Precipitation may occur as rain, fog drip, dew, snow, hail, sleet, or freezing rain. Figure 5 shows the average annual precipitation in various areas of the United States. Most areas within the continental United States experience from 100 to 150 days annually on which precipitation of 0.01 in. and above occurs. Arid areas of the western states experience fewer such days, averaging 30 to 80 annually. Heavy fog occurs in areas of the country roughly from 10 to 35 days annually, with extremes along the coastal regions, particularly in the Pacific Northwest and in New England. Fog consists of water droplets so small that their velocities of fall are negligible. Fog particles which contact an object may adhere to it, coalesce with other droplets, and eventually form a drop large enough to fall producing what is referred to as fog drip. On clear nights, the loss of heat by radiation from the soil causes cooling of the ground surface and the air immediately above it. Condensation of the water vapor present in the air results in a deposit of dew. The solid forms of precipitation, when melted either naturally or more quickly by the use of various salts, also produce surface moisture.

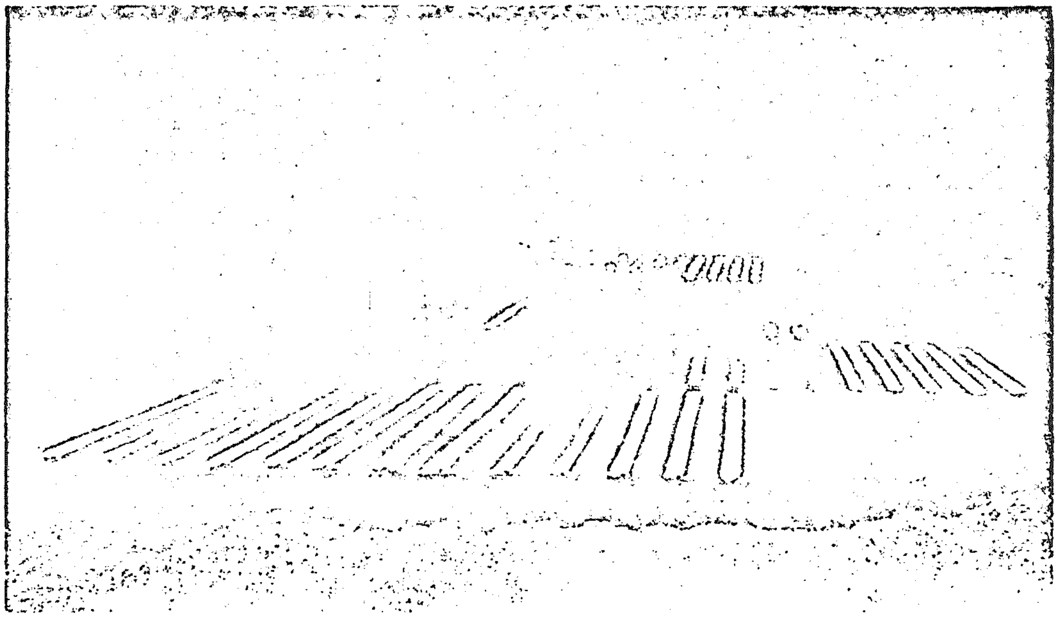


Figure 4. Water spray over raised, reflectorized markers at test site.

Table 1 gives the limits adopted by the United States Weather Bureau, above which precipitation is considered to be excessive short-duration rainfall (*1*). Figure 6 shows 1-hr rainfalls to be expected in the United States once on the average in 25 yr. Figure 7 shows the average annual maximum rainfall for 30 min.

Selecting rainfall rates for design purposes can be approached from a number of viewpoints, some of which require study and analysis considerably beyond the scope of this program. One could design for the worst conditions because the driver then needs the greatest visual help. The intensity of rainfall can become so great during short periods that light from the vehicle headlights begins to be scattered by the individual raindrops to the extent that visual perception is greatly impaired. This condition is not readily measured and requires further study. For this study, a precipitation rate of 4 in. per hr was chosen. It is probable that using this precipitation rate results in overdesign for many regions or locations. For example, the States of Nevada and Florida experience precipitations that differ greatly in amounts, but are quite uniform on a statewide basis; whereas, in Texas, amounts vary greatly across the State, not to mention differences in rates. Thus, these factors should be taken into consideration when designing a marking system for a specific location.

TABLE 1

LIMITS ADOPTED BY U.S. WEATHER BUREAU ABOVE WHICH PRECIPITATION IS CONSIDERED SHORT-DURATION RAINFALL

DURATION (MIN.)	DEPTH OF PRECIPITATION (IN.)	RATE (IN./HR)
5	0.25	3.00
10	0.30	1.80
15	0.35	1.38
20	0.40	1.20
30	0.50	1.02
45	0.65	0.84
60	0.80	0.78
80	1.00	0.78
100	1.20	0.72
120	1.40	0.72
150	1.70	0.66
180	2.00	0.66

Theoretically, a completely impervious and flat surface should have a runoff coefficient approaching unity. Capillary water in small pores, hygroscopic water absorbed on the surface of materials, and puddles of water stored in surface depressions result in runoff coefficients of less than unity for most surfaces. In hygrographic analysis, a runoff coefficient of 0.85 for pavements of asphaltic concrete and portland cement concrete is accepted (*2*). However, such information does not answer this very important point: "In a given rain, how deep a film of water can one expect on the road surface?"

Test Apparatus for Measuring Water Film Thickness on Pavements

In order to determine precisely the true water-film thickness that one might expect to encounter, an apparatus was designed for measuring water films at various rates of simulated rainfall. Measurement of water film is complicated by the high surface tension and capillarity of water. So as to avoid these characteristics and the problems associated with immersion-measuring devices, an

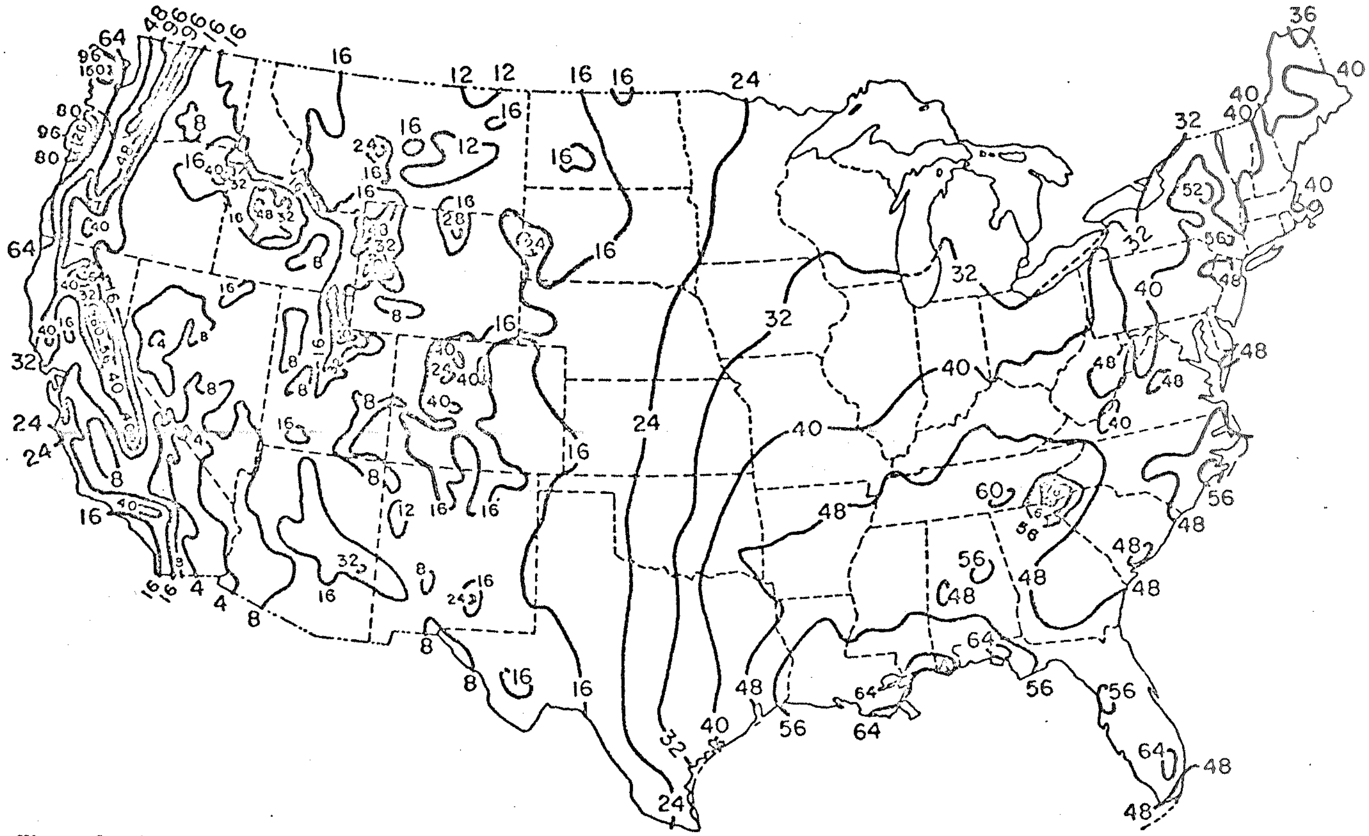


Figure 5. Average annual precipitation (in inches) in the United States (U.S. Weather Bureau).

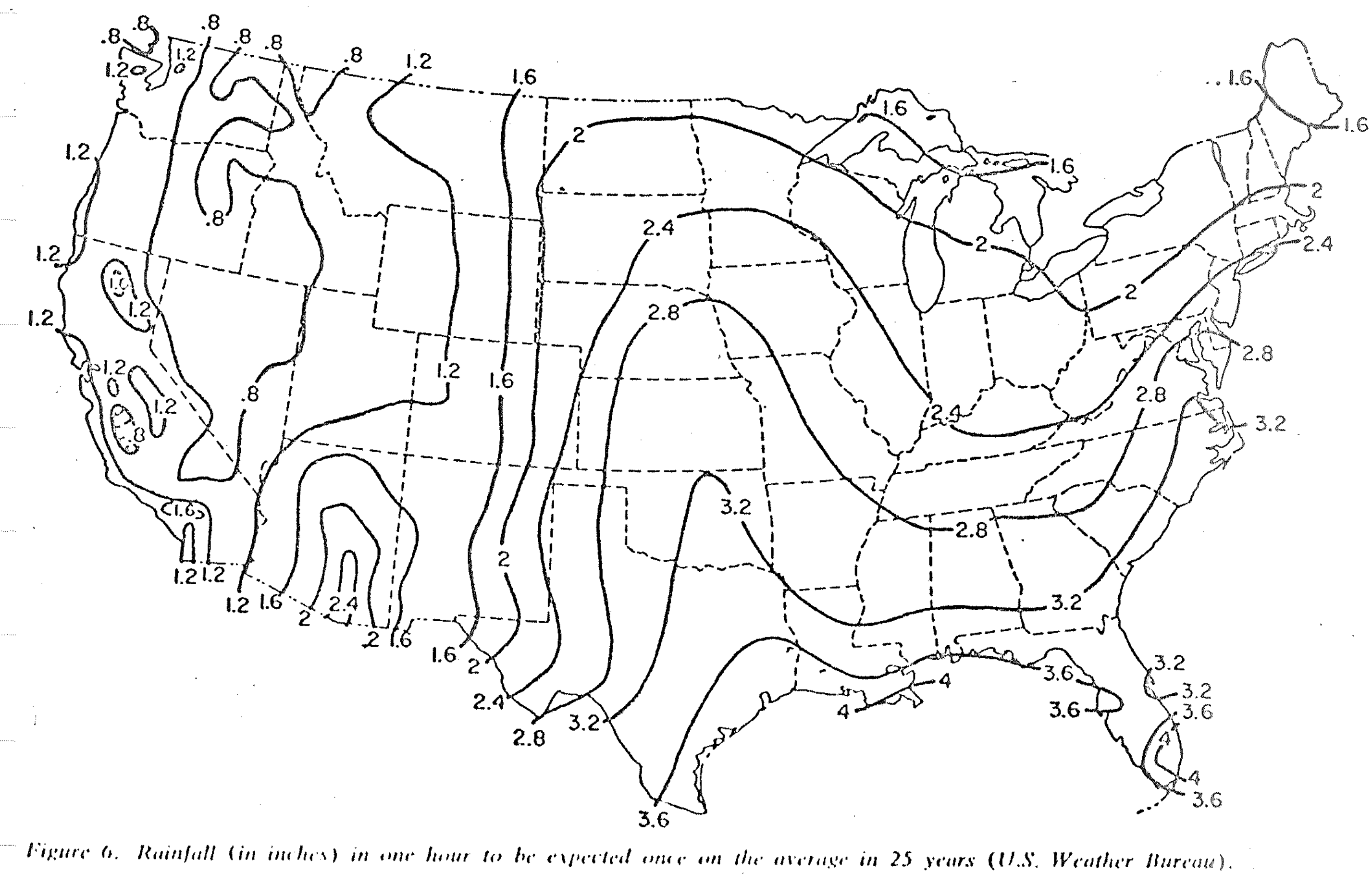


Figure 6. Rainfall (in inches) in one hour to be expected once on the average in 25 years (U.S. Weather Bureau).

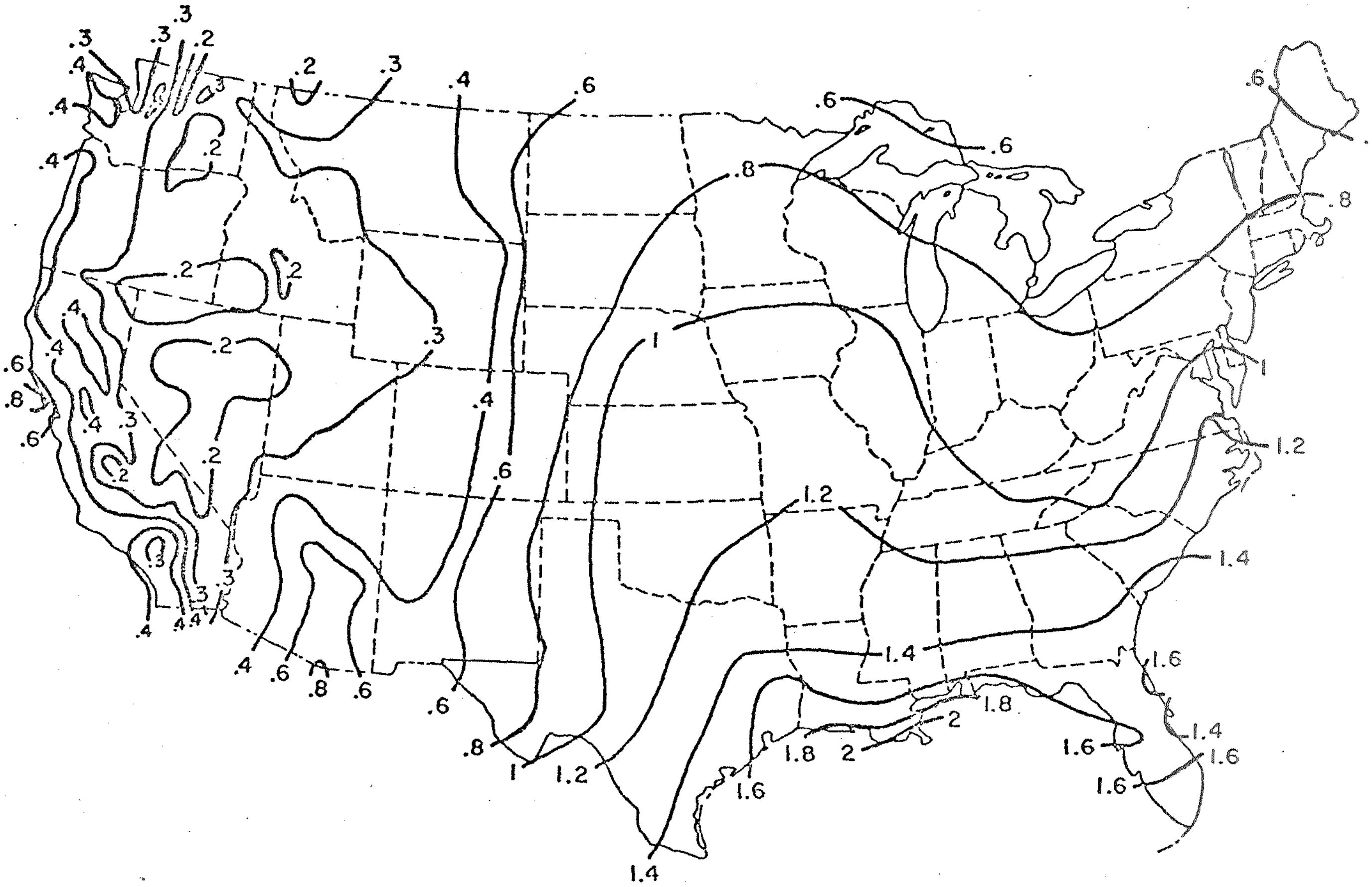


Figure 7. Average annual maximum rainfall (in inches) for 30 min (U.S. Weather Bureau).

apparatus consisting of a depth micrometer mounted on and protruding above a plate with supporting legs of rubber was designed. In this unit, shown in Figure 8, the micrometer was electrically insulated from the road. An insulated electrical conductor was attached to the micrometer and, hence, to a resistance meter. The other terminal of the resistance meter was connected to a heavy copper probe, which was laid in the water film on the road and in the vicinity of the micrometer. The micrometer was then turned downward until contact was made with the water film. Initial contact was sensed by watching the jump in the meter reading when the circuit was closed through the water film on the road. A reading of the micrometer was made at this point, and it was then turned downward until contact with the road was made—the difference between the two readings being the film thickness of the water. Figure 9 is a photograph of the water-film measuring apparatus and the spray rig being employed in the field. Because of the inherent unevenness of roadways, considerable areas of depression storage exist. It was therefore necessary to take a very large number of readings to arrive at representative figures. Studies of various water films on various characteristic pavements were made; these were further verified in studies of water films on a flat and very smooth surface especially fabricated for this purpose.

Runoff and Water Films on Pavements

Highway pavements may or may not be crowned. For those pavements that are crowned, the slope is generally 0.125 to 0.250 in. per ft. Shoulder slope is generally 0.750 to 1.500 in. per ft. The standard width of highways carrying large volumes of traffic is 24 ft.

The problem of a water film on a crowned two-lane rural highway is essentially one of the water falling on the marking material and flowing off in both directions so that there is little tendency for buildup from adjacent runoff. On a four-lane roadway carrying two lanes of traffic in opposite directions, with the road crowned in the center and marked there with double continuous yellow stripes and white skip lane lines, water falling in the center builds up a runoff pattern that crosses transversely the lane and edge lines. By selecting sites with the proper slope and contour, these conditions were simulated. By using the water spray apparatus at various locations where the pavement surface ranged from a very coarse to very smooth, as well as at one location having an extremely smooth surface of cement-asbestos, some 450 separate measurements of water-film thicknesses were made at simulated rainfall rate of approximately 4 in. per hr. It was found that on the crown of the road the average of all readings was 0.030 + 0.005 in. At the same rainfall rate, a location 12 ft downslope from the crown of the road with a downslope rate of 0.25 in. per ft, had an average water-film depth of approximately 0.040 + 0.005 in. These readings were made by using the artificially produced rain from the spray apparatus, but when rain occurred naturally, the occasion was taken whenever possible to go into the field and measure water-film thicknesses occurring on local county and State roads. The sporadic character of natural rainfall introduces certain uncontrollable variables into an analysis of data pertaining to it. However, there was good correlation among the thicknesses of naturally occurring water films and those produced artificially and those observed in earlier work by Izzard (*3*).

Other factors can influence runoff from a pavement but resist general interpretation. For example, "rainfall-disturbance," caused by variations in the rainfall drop size and intensity, can retard runoff, as can the character of the vegetation growing on the road shoulder.

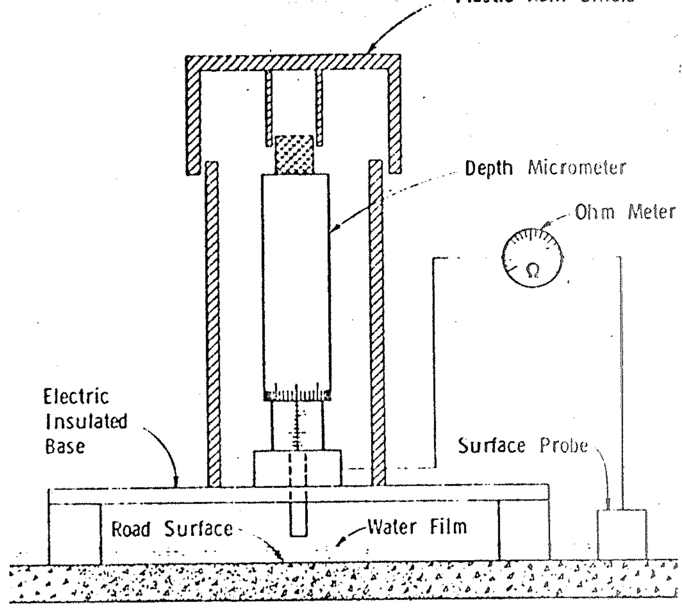


Figure 8. Schematic of device for measuring water-film thickness.

GLASS BEADS IN PAVEMENT MARKINGS

Physical Nature of Glass Beads

Reflective glass beads used in highway marking are largely produced from glass cullet or scrap, which is ground, heated sufficiently to allow surface tension to pull each individual particle into a spherical shape, cooled, sieved, and bagged for use. It should be noted that this manufacturing process lends itself to the production of beads of a mixed gradation of sizes rather than of uniform single size. Much of the glass used in making beads has a high silica content and a relatively low refractive index (1.5), whereas glasses of higher refractive index (1.9) generally have lower silica contents and lower chemical durability, but not necessarily lower serviceability (*4*). The glass from which beads are made is very hygroscopic. Thus, glass beads have a built-in affinity for water, which not only causes problems in their application but also makes them actively seek water in the highway environment. This result is exactly opposite of what is desired. Beads in a container opened on a day when the relative humidity is high will absorb moisture and lose their free-flowing characteristics. When an attempt is made to apply them as a reflective medium to a highway marking material, they will have a tendency to fall as groups of beads rather than as individual beads. It is not uncommon for the beads to clog the bead-dispensing apparatus so that these dispensers must be unclogged before striping can be continued.

The hygroscopic constituents on the surface of the glass beads are alkaline in nature. One of the earlier methods of producing a free-flowing glass bead was to inject sulfur dioxide into the process stream or into the containers holding the beads. Although this addition solved the problem, it presented several difficulties in practice and was largely discontinued. Afterward it was found that various absorbent powders added in very small amounts were efficient in making glass beads free-flowing.

Further development work resulted in the use of silicone products to make the beads free-flowing. Processes for applying the silicone treatment vary; the silicones may be introduced as a gas phase during manufacture of the beads or they may be applied after the beads are produced. The silicone treatment results in a bead that has water-repelling characteristics. For example, silicone-treated beads dropped into water will agglomerate and hold with them bubbles of air for an extended period of time. Further, immediately after silicone-treated beads are dropped onto a painted highway stripe, any water falling

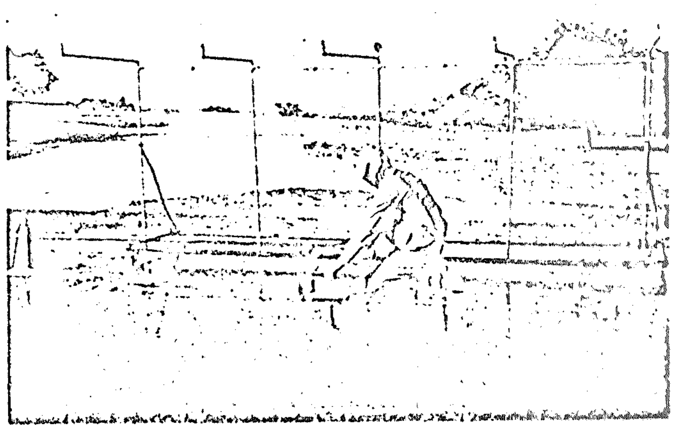


Figure 9. Measuring water films in the field.

on the stripe will, because of its surface tension and the repellency of the silicones, bead up into small individual pools. There is some indication that some of the silicone on the beads might actually migrate off the beads and onto the surface of the paint film. When the water does bead up, there are many areas which are free of a submerging film of water, and the retroreflective elements are active and are fully retroreflective.

Experiments were conducted to determine the duration of effectiveness of the silicone treatment in the actual roadway environment. A series of stripes was put down, and the silicone-treated beads applied to them. After this, the water-spray rig was set over these stripes and run intermittently during the daylight hours. After 3 days of this exposure, the water repellency of these stripes had diminished to the point where the water would no longer bead on the surface, and the retroreflective elements became submerged and no longer active. Although this treatment offers a significant and very useful function in terms of nighttime visibility, the shortness of its life greatly diminishes its significance. Because of its potential, some of the better known and most effective water-repellent silicone fluids were obtained and mixed with a paint binder in proportions of 1, 2, and 3 percent by weight. These binders were then applied and subjected to water spray, as were the stripes with silicone-treated beads. It was found that the treated binders beaded water nicely initially but, like the silicone-treated beads, after 3 to 5 days' exposure became ineffective and the stripes again became subject to continuous submerging water films.

GRADATIONS OF BEADS

State highway department specifications for drop-on-type glass beads for reflectorizing paint markings call for the typical gradations given in Table 2.

Specifications for drop-on-type glass beads for reflectorizing hot-extruded thermoplastic markings call for the typical gradation given in Table 3. Specifications for glass beads used as an admixture with paints and thermoplastics call for a mixed gradation of beads of a smaller size than are called for in the drop-on application.

THICKNESS OF BINDERS

More than one-half of the State highway departments apply their bead binder paints at a spreading rate of over 16.5 gal per mile of continuous 4-in. wide line. This amounts to a wet-film thickness of approximately 15 mils. One-fourth of the State highway departments apply their bead binder paints at a wet-film thickness of over 16.5 mils.*

The hot thermoplastic marking materials are generally applied at a film thickness of 125 mils.

APPLICATION RATES FOR GLASS BEADS

The standard application rate for glass beads is 6 lb of beads per gal of paint. In some instances, it is the practice to premix 4 lb of beads with the paint and apply this, dropping on 2 lb per gal during application on the basis that the 2 lb dropped on will give immediate reflectorization and later with abrasive wear the premixed materials will come into service. Figure 10 is a photomicrograph of a highway marking paint with a beads-on application.

Retroreflective Characteristics of Glass Beads, Dry

RETROREFLECTION AS A FUNCTION OF BEAD IMBEDMENT

So as to more clearly demonstrate how retroreflection takes place in a pavement marking material at a location where the vehicle light makes a very small angle with the pavement, a series of large glass beads with a low refractive index were coated to various depths in a standard highway-marking, bead-binder paint. In Figure 11(*a*), a series of these beads is viewed from the source of the incident beam and on the horizontal with the plane of imbedment. The bead on the left received no coating, the second bead from the left was coated to 50 percent of its vertical height, the third bead was coated to 60 percent, the fourth to 70 percent, and the final bead to 80 percent. The bead imbedded to 60 percent of its vertical height shows a high degree of reflectance and a large active area. As the depth of imbedment increases, the angle which the light makes with the surface of the bead decreases, and a growing percentage of the light is reflected off the surface rather than being refracted. Furthermore,

* Private communication, The Sulphur Institute (June 1964).

TABLE 2

TYPICAL GRADATIONS FOR DROP-ON-TYPE GLASS BEADS FOR REFLECTORIZED PAINT MARKINGS

U.S. STD. SIEVE NO.	SIEVE OPENING (IN.)	TYPICAL SPECIFICATIONS (% PASSING) EXAMPLE NO. 1	EXAMPLE NO. 2	EXAMPLE NO. 3	EXAMPLE NO. 4
20	0.0331	98–100	100	100	100
30	0.0232	60–90	75–95	95–100	75–90
50	0.0117	15–50	15–35	10–35	15–30
100	0.0059	0–10	0–5	0–5	0–5
200	0.0029	0–5	0–1	0	0–1

TABLE 3

SPECIFICATIONS FOR DROP-ON-TYPE BEADS FOR REFLECTORIZING HOT-EXTRUDED THERMOPLASTIC MARKINGS

U.S STD. SIEVE NO.	SIEVE OPENING (IN.)	PERCENT PASSING
20	0.0331	90–100
35	0.0197	0–10

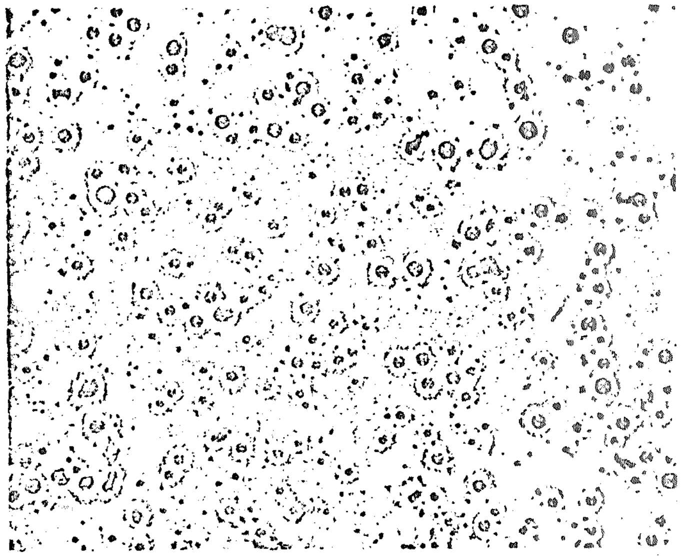


Figure 10. Photomicrograph of a paint stripe with beads applied by drop-on method.

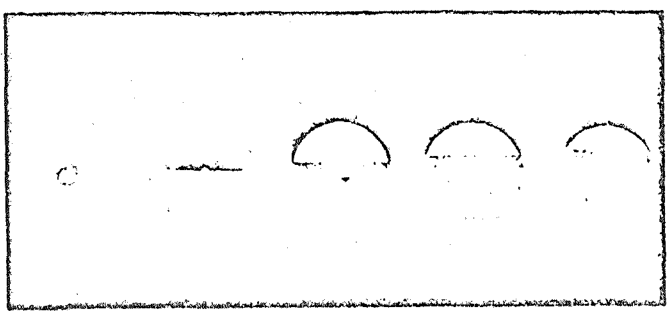
the total area of the bead available for retroreflection declines. Figure 11(*b*) is a photograph of the same beads as shown in Figure 11(*a*) under the same illumination and at an approximate angle of 135° with the incident beam. In this photograph, both the change in the active portion of the beads and the focal areas on the back of the beads can be seen quite clearly. Since the angle of light thrown by a vehicle headlight on the pavement diminishes rapidly as the distance in front of the vehicle increases, the possibility of focusing in the lower half of the bead declines accordingly. Any retroreflection that then takes place must occur in the upper hemispherical section of the bead; for this to occur, the binder must be above the horizontal axis of the bead. Thus, imbedment above the horizontal axis of the bead is not only important for good retention in the binder but also for good retroreflection at increased distances. The current practice of dropping a mixed gradation of beads into a binder of constant thickness results in efficient retroreflection in only a small percentage of the beads applied.

From these experiments, it was indicated that, as the angle the light makes with the pavement decreases, the lower half of the vertical height of the glass bead contributes little to the retroreflective capabilities of beads in the highway environment; it was desired to demonstrate this in a more complete manner. For this demonstration, two identical large glass beads were obtained, and one of these was cut in half. The whole bead was coated to 60 percent of its vertical height. The hemispheric portion of the other bead with its cut face down was coated to 10 percent of its vertical height, and the two were mounted so that the tops of the coatings were in the same horizontal plane as the light source.

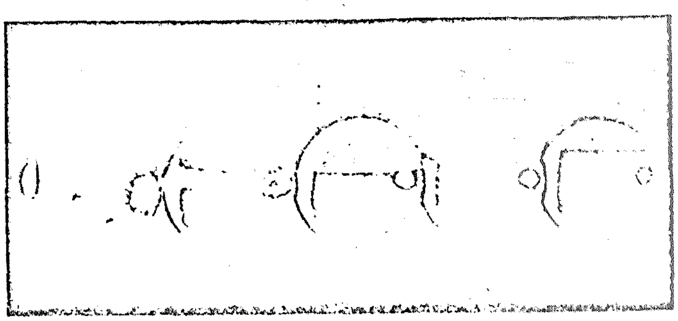
In Figure 12(*a*), these two beads are viewed from the source of the incident beam and on the plane of imbedment. The half bead is on the left; as can be seen, it shows the same degree of retroreflectance as the full bead. In Figure 12(*b*), the same two beads under the same illumination are viewed at an approximate angle of 135° with the incident beam.

RETROREFLECTION AS A FUNCTION OF BINDER ORIENTATION WITH THE LIGHT SOURCE

Since the angle at which the automobile headlights impinge on a retroreflective highway-marking material is extremely small and subject to little alteration, an experiment was set up to determine the feasibility of altering the orientation of the binder on the bead with respect to the plane of the headlights. Figure 13(*a*) is a view, from the source

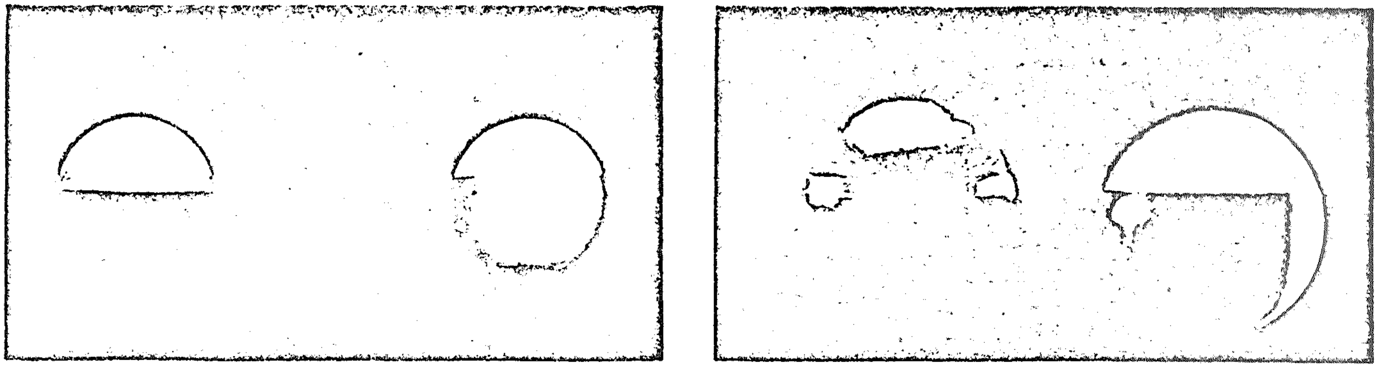


(a)



(b)

Figure 11. Beads imbedded in binder to various depths



(a) (b)

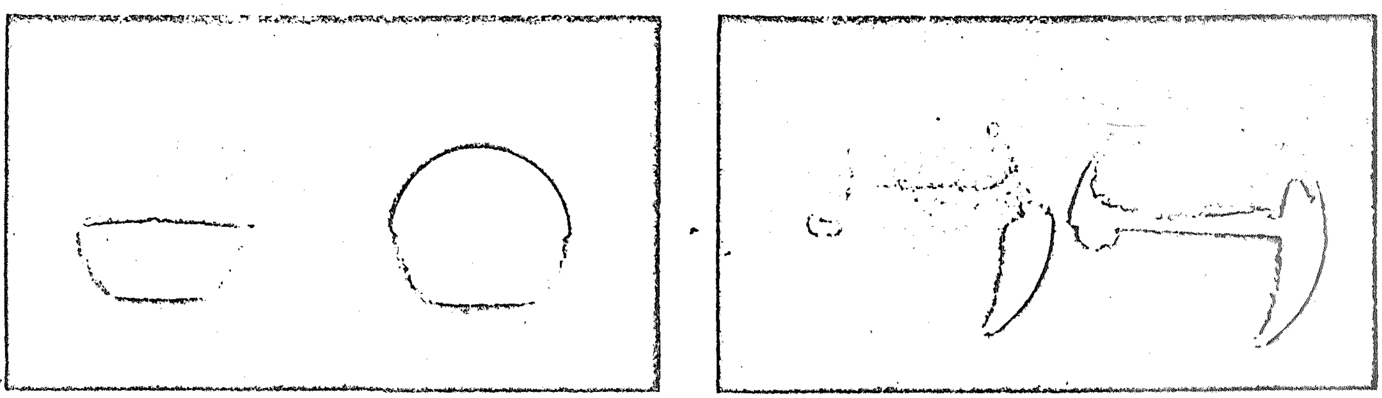
Figure 12. Retroreflectance of hemispherical sections of a half and a whole glass bead.

of the incident beam, of two identical large beads which have been imbedded to 50 percent of their height in a bead binder, with the bead on the left imbedded in the same plane as the light source. The bead on the right has been tilted forward approximately 3°, raising the binder on the back and lowering it on the front. This effect is quite dramatic. In Figure 13(*b*), the same two beads are viewed at an approximate angle of 135° with the incident beam.

When a glass bead is dropped into a marking material, such as paint, surface tension causes the paint to climb up the side of the bead. This capillary rise is influenced by a number of variables, including the contact angle, the surface tension and viscosity of the marking material, and the wettability or surface treatment which the bead may have received. Both surface tension and viscosity may vary with temperature. The capillary attraction of liquid to glass beads manifests itself in an interesting manner in that experiments in the laboratory indicate that if one lays a marking material in a horizontal position and begins to apply beads under pressure in a vertical direction and then alters the direction of application from vertical to a very shallow angle, the encapsulation of the beads is for all practical purposes the same. In another experiment, the painted surface was positioned at various angles from the horizontal, and beads were again applied by pressure at various angles. Again the beads were found to be encapsulated in the same manner; that is, the paint had risen to the same height around the bead with respect to the plane of the painted surface. Thus, these experiments indicated that orientation of the beads to give maximum retroreflection in one direction occurs more readily on an inclined surface which faces the light source.

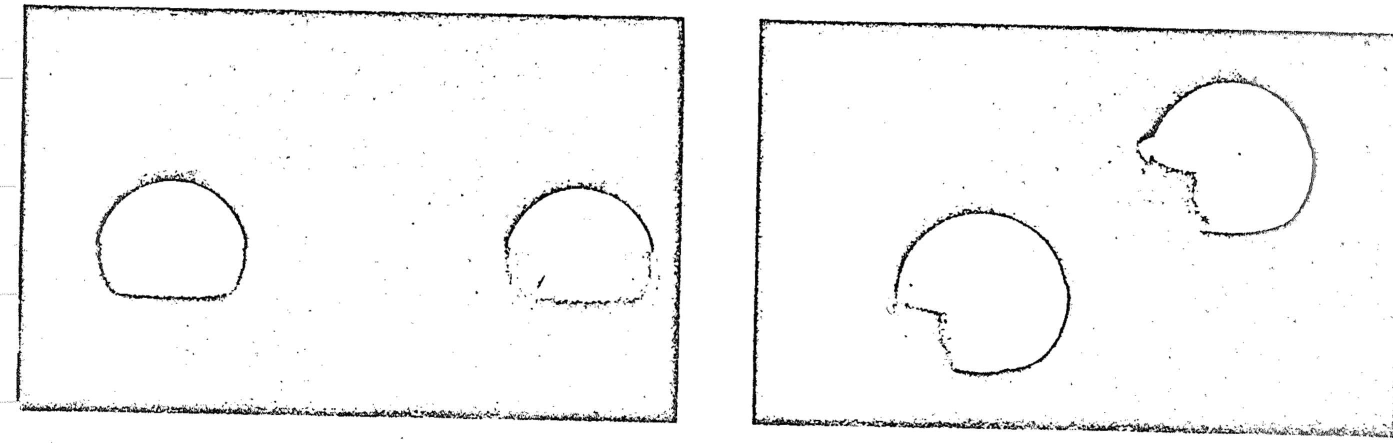
RETROREFLECTION AS A FUNCTION OF MIXED BEAD SIZES IN A CONSTANT-THICKNESS BINDER

Since beads are commonly applied as a gradation of a variety of sizes in a paint-film binder of constant thickness, it was desired to ascertain the influence of the various size beads upon one another (*4*). To do this, two large beads of the same diameter were coated to 60 percent of their height and placed side by side. Three smaller beads, each with a diameter approximately 75 percent that of the larger bead, were coated to a height equiva-



(a) (b)

Figure 13. Retroreflection as a function of binder orientation.



(a)

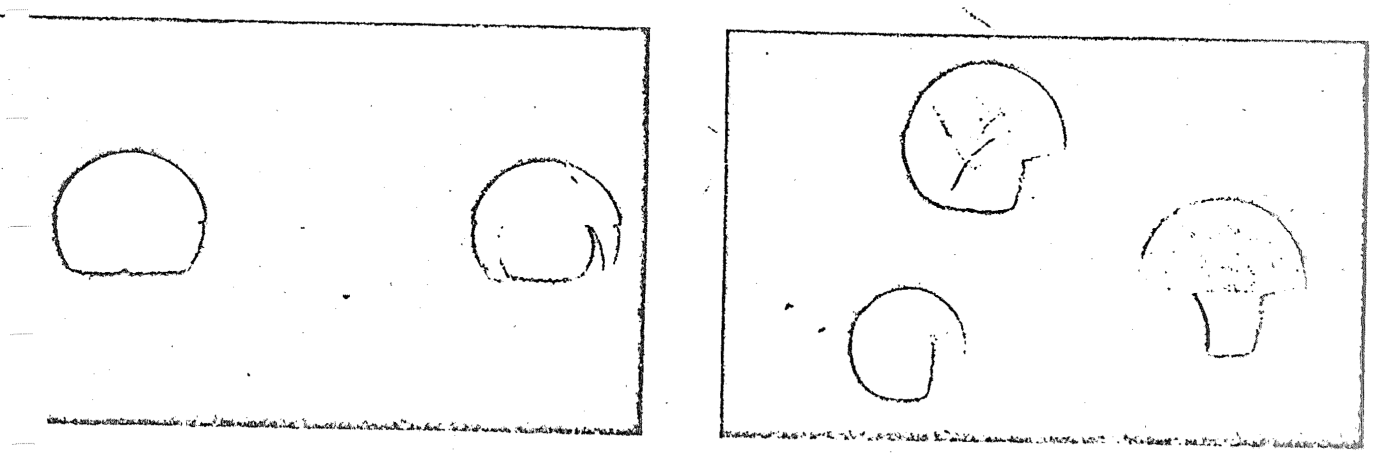
Figure 14. Small beads behind large beads.

(b)

ent to the coating height of the larger beads (as they might be if dropped into a binder of a uniform film thickness) and then placed behind one of the large beads. In Figure 14(*a*), the two large beads are viewed from near the source of the incident beam with the three smaller beads located directly behind the large bead on the right. The smaller beads do not contribute to retroreflection. Figure 14(*b*) is a view of the same beads shown in Figure 14(*a*), but at an approximate angle of 135°. It shows the smaller beads lying in the shadow of the larger bead in front of them. In Figure 15(*a*), the two large beads are viewed from near the source of the incident beam; but, in this instance, the three smaller beads are placed in front of the large bead on the right. Figure (*b*) is a view of the beads in Figure 15(*a*), but at an approximate angle of 135°; note how the first little bead, which is too deeply imbedded to present anything but its least effective area to the light source, blocks out the remaining two smaller beads and also the most effective area of the large bead.

RETROREFLECTION AS A FUNCTION OF REFRACTIVE INDEX, SHAPE, AND IMPERFECTIONS

As the refractive index of the glass is increased from 1.5 to 1.9, the focal point of the refracted light progresses from outside and to the rear of the bead toward the back inside surface of the bead. Thus, as the refractive index is increased, a great deal less scattering occurs and retroreflective efficiency improves directly. The shape of the beads is also an important variable in that any deviation from the true spherical shape destroys the in-line focusing ability of the bead. Imperfections in the glass may be caused by striae (which are streaks or veins due to the composition differing slightly from the average), or bubbles (that were trapped in the melt and could not escape), or stones (small fragments of undissolved material), or crystallized bodies (which precipitated out during cooling), or cloudiness (from turbidity in the melt), or other irregularities. All are undesirable and have an adverse effect on the retroreflective capabilities of the glass.



(a)

Figure 15. Small beads in front of large beads.

(b)

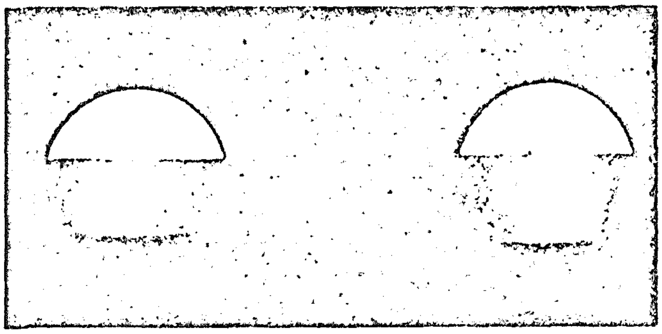


Figure 16. Thin coating films of water on beads.

Retroreflective Characteristics of Glass Beads, Wet

THIN COVERING FILMS OF WATER

In demonstrating the influence of thin covering films of water, two large beads were coated with a paint binder to 60 percent of their vertical height and mounted side by side. A water source was mounted over one of the beads, and a continuous stream of water droplets was allowed to fall on the bead, covering it with a thin film of water at all times. Figure 16 is a view of these two beads from near the incident beam source, with the water-coated bead on the left. A water meniscus can be seen around the base of this bead. The bead on the right is dry except for several small splash droplets on the side facing the bead being wetted. The significant point to be drawn from this demonstration is the fact that a thin film of water covering the bead has a relatively minor influence on its retroreflective capabilities.

THICK SUBMERGING FILMS OF WATER

In another experiment large glass beads were coated to various heights with conventional paint binders and placed in a submerging film of water so that their upper surfaces did not protrude when viewed from near the light source. Their presence beneath the water surface was imperceptible. As their height was increased to the point where they rose above the surface of the water, though they were still covered with a thin film of water, they again became retroreflective, poorly at first but showing improvement as they were raised progressively higher.

WATER FILM CHARACTERISTICS AS A FUNCTION OF BEAD APPLICATION DENSITY

Water has a strong tendency to rise up on the sides of materials, like glass, that have an affinity for it. Where the surface density of glass beads in a binder is very high, the wetting characteristics of water help to bridge the gaps between beads. Furthermore, a high-density application of the beads leaves fewer channels for the water to flow away from the beads; thus, submerging films are more easily achieved in high-density applications of beads than in moderate applications. In demonstrating this, a series a stripes was prepared in which the density of beads was continuously increased until the surface became completely saturated with beads. When the series was subjected to simulated rainfall, the stripe saturated with beads was the first to lose its retroreflective capabilities.

CHAPTER THREE

INTERPRETATION OF FINDINGS

MARKING PRACTICES AND DAY AND NIGHT VISIBILITY

Because reflective materials are only a part of the marking material system, their effectiveness and the length of their service are direct functions of the life of the marking material itself, since it is acknowledged that the reflective materials often contribute to this life. In looking at the use of marking materials in 50 different States, each of which may have climatic conditions that vary widely within it, and each of which has different specifications for paving materials with varying traffic densities and road surfaces, it may be seen that failure of paint and marking materials can be manifested in a variety of ways. Interestingly, all of the States have adopted bead-gradation specifications that are essentially the same. However, one must consider the mechanism of paint failure before selecting an optimum bead system and gradation. If the paint fails by abrasion and erosion or a combination of both, as described in American Society for Testing and Materials (ASTM) publication D821–47, then the smaller size beads become exposed and active and the larger beads become dislodged. If, however, the paint fails by developing cracks or chipping off, as described in ASTM Traffic Paint Test D913–51, then the smaller beads never have the opportunity to become active. Concrete pavements, being porous, allow water to rise up through them; this action plus the highly alkaline environment contribute to the often observed more rapid failure of paints on concrete through loss of adhesion. Thus, paint failure of this character would not allow the larger percentage of the glass currently being used to become active. At other locations, such as on rural roadways where traffic directly over the stripes is at a minimum and where road surfaces are generally much coarser in character, marking paints often fade or after a while become dirty. It is necessary to repaint them annually, even though physically they are still largely intact, except possibly on the surfaces of the uppermost pieces of aggregate, where they may have worn away. Again, a large percentage of the glass may never become active. Another type of paint failure is that caused by erosion. Wind, sand, and other environmental conditions allow a slow and steady erosion of the marking material, particularly those having built-in chalking characteristics. Very often, the road surface itself is covered by film that is not readily apparent; but by wetting a finger and rubbing the road, one can appreciate the extent of these films. Preconditioning the road surfaces to be marked is practiced infrequently; therefore, paint is often applied over road film, adhesion is poor, and the paint fails by breaking away.

In the summer months, marking materials can fail when the bituminous materials feed up from the substrate or when road film deposited by vehicle tires completely covers up the markings. Marking materials that have received a dropped-on application of beads exhibit a far greater tendency to pick up road film than do unbeaded materials. It is not uncommon to find stripes in some of the warmer areas of the country where road film from tires has made the markings completely indistinguishable in the daytime. Paradoxically, these same markings at night can be very attractive because they retroreflect the binder color on the inside backs of the glass beads. Physically, these markings can be 100 percent intact; yet they have failed in terms of delineation of the roadway in the daytime, and only a small percentage of the incorporated beads has been utilized for retroreflective purposes at night.

Thus, for a marking material of limited thickness that loses its upper surface with time, a bead system of varying gradation is most desirable. On the other hand, where markings fail by mechanisms other than loss of their upper surfaces, a bead system with the bead gradation approaching a single size matched to the binder thickness would be more desirable. It should be remembered that improvements in matching wearing characteristics with film thicknesses and bead gradations that range from 0.005 to 0.040 in. in diameter, as currently used, cannot be expected to provide good visibility at night during periods of precipitation.

Day and Night Visibility, Dry

Unreflectorized surface markings such as paint may be characterized as being a highly effective means of delineating roadways that command driver attention and response during daylight hours but an ineffective means of delineating roadways at night under vehicle headlight illumination. The surface marking system is one lending itself to high-speed application of markings that conform to existing surface contours as a film and thus do not present themselves so prominently for damage by snow removal and other maintenance equipment.

In dry weather, the use of reflective glass beads is an effective means of providing visibility to surface markings at night under vehicle headlight illumination. Glass beads also lend themselves to high-speed application that can be performed in conjunction with the application of the surface markings. Glass beads applied to surface markings detract from the daytime visibility and appearance because they cause surface reflections and result in an uneven surface texture that allows dirt and road film to be picked up and held. The glass beads focus sunlight and produce heat that can cause bleeding of the substrate into the marking material.

Just as light impinges on a water film and is reflected forward and lost, there are a number of phenomena that can aid or hinder the driver in distinguishing the roadway. Both early in the morning and late in the evening, when the sun is just above the horizon and the motorist is driving into the sun, glare or reflections glancing off the roadway and into the driver's eyes make it very difficult for him to perceive surface markings. During these same periods, when the driver is driving with the sun over his shoulder, it is not uncommon for the sunlight to be focused in the reflective materials on the roadway and directed back to the driver, thus improving the daylight visibility of the markings.

Raised, unreflectorized markers, such as buttons, may be characterized as an effective means of delineating roadways that command driver attention and response during daylight hours, but are ineffective at night. The reflectorized types are very effective at night; but high-speed techniques for their placement have not been fully developed. Markings that rise above the surface contour of the road are subect to damage by snow-removal equipment. A recent approach to this general problem is a raised marker mounted in a suspension system that is buried in the pavement; in operation the portion of the marker rising above the surface contour of the road deflects down and out of the way when subjected to an external force and then returns to its raised position. The unit is self cleaning of ice and snow. Another approach to this problem is the use of snowplows with flexible blade attachments and other devices to protect the markers. Raised markers must generally be removed before resurfacing operations can be conducted. Raised markers are also subject to damage by tire chain and winter tires equipped with studs. Nearly 5 million of the 16 million new snow and ice tires sold during the 1966-67 winter were equipped wih studs (*5*). The nature and extent of this damage to all types of markings have not been ascertained.

Unbeaded Stripes

The current practice of dropping glass beads on highway marking materials is a recognized compromise to gain night visibility at a detriment to the appearance of markings during the day. A variety of practices has been employed to strike a balance between the daytime attractive ness of the unbeaded stripe and the need for retroreflectance at night. The application of beads to one half of the length of a 15-ft center or lane line has been employed; this gives a reflective stripe at night, yet leaves a portion of the stripe unbeaded and attractive in appearance during the daylight hours. Others have employed the practice of dropping on reflective materials over the entire length of the stripe but only over one half of the stripe's width. Some municipalities, in striping downtown areas, reason that the majority of the people are downtown during the daylight hours; therefore, they seek to have their markings in their most attractive state at that time and, therefore, do not bead the stripes. The need for retroreflectance of markings at night is paramount to driving safety; thus, compromising appearance to gain retroreflectance is well justified. The deterioration of the appearance of the paint marking materials with the application of glass beads has been observed and documented throughout the entire field test program. The development of a retroreflecting system that would not detract from the daylight visibility of the marking material would be advantageous.

Intermittent Black Contrast Lines

Often a condition arises wherein there is a very poor degree of contrast between a white beaded paint stripe that has picked up road film and deteriorated in color, and the pavement itself. This condition is very evident on many concrete pavements. It does not manifest itself quite so rapidly on asphaltic pavements; but, given time, it can be observed as the asphalt recedes to expose more and more of the aggregate. This condition is more evident where limestone and similarly light-colored aggregates are employed. So as to improve the contrast of white center lines and lane lines, it has been the practice in certain areas to lay a black stripe of paint or bituminous material in the interval between the white paint stripes; sometimes this stripe is overcoated with a drop-on application of a black aggregate, such as basaltic rock. This black line, particularly on concrete pavements, greatly improves the contrast and often is far more visible in the daytime than a white stripe, particularly one that has lost its initial brilliance.

Depth of Bead Imbedment

As discussed in the previous chapter, there is an optimum depth of imbedment that allows glass beads to furnish the maximum retroreflection and area of retroreflection. This depth was found to range from 55 to 60 percent of the vertical height of the bead. Beads imbedded to less than half of their vertical height in ordinary binders have insufficient mechanical imbedment to prevent them from being dislodged under traffic. The available area and intensity of retroreflection are greatly reduced if the beads are too deeply imbedded. Bead size, paint film thickness, and capillary action largely control depth of imbedment in the conventional systems. Another possible approach to imbedment depth is to surface treat the beads so that surface forces between the bead and the binder will prevent the bead from being completely submerged in the binder.

Direction of Application

It was shown in the previous chapter that if a bead is imbedded in the binder so that the binder is low on the side of the bead facing the incident light and elevated on the side away from light, improved retroreflectance will be observed. Experimental work has shown that glass beads orient themselves in a binder in essentially the same manner irrespective of whether the binder is in a horizontal or vertical position or whether the beads have been applied directionally. This orientation is due largely to the capillary action of the paint on the beads. Thus, for smooth horizontal surfaces, directional application offers few, if any, advantages. If the surface to be marked is irregular rather than smooth, much of the surface will be inclined toward the light; glass beads on this surface will be favorably oriented with respect to retroreflection. In the field, it was noted that vertical application of beads by a machine moving over an irregular surface resulted in a painted stripe with greater reflectance when viewed from the same direction the striping machine followed than when viewed from the opposite direction. Following this, an experiment was conducted in which beads were dropped vertically onto a line from a striping machine on a seal-coated surface by a hot oil-asphalt application, followed by dropping on a crushed aggregate ranging in gradation from 0.250 to 0.125 in. Close inspection of this stripe revealed that vertical application of beads from a moving machine onto an irregular surface resulted in a large percentage of the beads being dropped on the forward or front side of the aggregate, as viewed from the direction which the striping machine followed. For center and lane lines of one-directional traffic, this feature could be employed to advantage. For multiple-direction arteries, angling the bead dispenser to the rear away from the machine and pressure application of beads so that their fall velocity is as close to vertical as possible offer a technique to more evenly distribute the glass on both sides of the aggregate particles and thus provide a line with more equal reflectance in both directions.

Bead Gradation

Gradation of beads, as discussed in the previous chapter, indicates that most of the glass being used in the country today is material that passes a No. 30 sieve and holds on a No. 50 sieve, giving it an average diameter of approximately 17 mils. Current paint application film thicknesses range from 16 to 20 mils. Because of the optical characteristics of glass beads, there is really only one optimum bead size, for a given paint film thickness, to give maximum retroreflection. Thus, today's bead gradations are designed for use in markings that usually fail by abrasion or wearing away. Because there are many other mechanisms of paint failure, there is considerable justification to question the current practice.

Refractive Index

The use of glass of a high refractive index shows a progressive improvement in terms of retroreflection as the refractive index increases from 1.5 to 1.9. The difference is principally one of degree, which can be measured. Where comparative stripes having glass beads of high and low refractive indexes are laid, the improvement is most distinguishable and easily recorded photographically. Without comparative stripes, only the more trained eye is apt to be able to distinguish the differences in refractive index of the glass in a painted line. As the refractive index of the glass increases, the focal point progresses from the back and outside of the bead to the inside. Therefore, color and character of the binder have a diminishing influence on retroreflectance.

Day and Night Visibility, Wet

During daylight hours, precipitation very often improves delineation of the roadway by improving the contrast between the road surface (which is generally darker when wet than the marking materials) and the markings. During darkness in urban areas, overhead lighting is very often reflected off the road surface toward the driver, and markings are less distinguishable than in a rural environment with few or no foreign light sources.

Conditions of moisture in the nighttime environment produce effects which are almost entirely detrimental. In addition to wetting and submerging the marking materials and their reflective elements, the light from approaching automobiles is reflected off the water on the pavement surface and forward to the approaching vehicle; which greatly magnifies the headlight glare problem and makes surface-marking materials more difficult to perceive. The marking materials on expressways and major thoroughfares, which have very smooth surfaces when new and become even smoother with age, are subject to frequent restriping and are the first markings to lose their effectiveness when wet. On the other hand rural roads that have been given a seal coat with large aggregate, followed by the application of reflectorized paint markings, can be almost as effective when wet as when dry because much of the reflective material is elevated on the large pieces of aggregate; thus, only under extreme rainfall conditions does this material become submerged.

Raised, reflectorized markers offer an effective means of providing visibility at night under dry and wet conditions. Not all raised, reflectorized markers perform well when wet, but those that do are effective up to the point when the precipitation becomes so intense that it begins to scatter the light as does fog.

Regular Elevation of Area to Be Marked

It was desired to determine if simple elevation of the area to be marked would improve the retroreflection of the marking materials at night in the wet condition. To determine this, a series of stripes was laid wherein a smooth base coat of a modified, molten, elemental sulfur was applied to the road in thicknesses ranging from 30 to 90 mils, thus providing an elevation completely above the 30 to 40 mils of water film that one encounters during periods of precipitation. These stripes were then painted with a dropped on beads application using the standard bead gradation and viewed under simulated rainfall. It was found that the reflective elements in the beaded stripes became submerged and ineffective. It was further found that, on discontinuance of the rain, these stripes recovered their ability to retroreflect far more rapidly than adjacent stripes that were unelevated. This might have been expected, since the elevated stripe did not prevent submergence of the reflective elements but did allow the submerging film of water to flow off the stripe in an easy path, therefore exposing the retroreflective elements again. Regular elevation of the stripe did not provide a solution to having a visible stripe during periods of precipitation.

Irregular Elevation of Area to Be Marked

A second means tried for elevating the retroreflective media out of the submerging water film was that of applying a coarse aggregate precoat to the area to be marked. This was done by seal-coating with asphalt and various rock gradations up to materials passing a 0.500-in. sieve. Conventional beaded paint stripes were then applied over these areas. It was found that these stripes were reflective either wet or dry. This suggests the precoating of areas to be marked with a seal coat of aggregate of sufficient size to protrude up through the water films before conventional markings are applied.

Use of Large Beads

Since water films on roadways have certain definable thicknesses, it therefore becomes practical to consider the use of beads of sufficient size to extend up through these submerging films and thus be retroreflective when wet. As the size of the beads is increased, the area of retroreflection per unit weight of glass decreases, since in a sphere the area increases by the square of the diameter and volume increases by the cube of the diameter. If one is to employ beads of the larger size in paint, it is necessary that the film thickness of wet paint be correspondingly increased. In general application, highway-marking paint binders tend to form a surface film and have an extended drying time when applied in increased thickness. The physical and mechanical forces imposed on the binder become correspondingly greater as the size of the beads increases.

Since the thermoplastic marking materials are currently being applied at a thickness of approximately 125 mils, the opportunity to go to larger size beads that will project up through the submerging films of water is a simple, straightforward solution. Currently, the practice is to use essentially the same bead gradation in the thermoplastic materials as is being used on paint; therefore, this solution is apparent and begging for application. Many of the thermoplastic marking materials are filled with fine aggregate and have mechanical properties considerably in excess of those of paint binders.

Use of Small Beads on a Carrier

Since for a given weight of glass the area available for retroreflection is much larger for small beads than it is for larger beads, there are considerable advantages in using small beads. However, the use of smaller beads would require much thinner paint films at a detriment to the hiding power and the life of the paint; they would also be more easily submerged by rain than materials currently being used. This suggests the application of small beads as a continuous and covering coating to some carrier, the size of the carrier and the size of the coating beads being selected for the specific application. By selecting a carrier that does not necessarily have to be perfectly spherical in shape and coating its surface with a covering of small beads, one can obtain an equivalent area of retroreflection using as little as one tenth the volume of glass of a single sphere of equivalent size.

Several experiments were conducted on methods for applying a coating of small beads to the surface of a carrier. The carrier can be one of a variety of materials so long as it has good structural integrity and preferably a specific gravity greater than that of the glass. In this work, a pea-gravel aggregate passing a 0.250 in. mesh and holding on a 0.125 in. mesh was used. This material was washed and dried and then charged to a rotating drum mixer equipped with internal flights; the axis of the drum was inclined to approximately 25 deg from the horizontal and rotated at a speed of approximately 36 rpm. Conventional highway marking paint was added to the aggregate until it was wetted but not flooded. As soon as the aggregate was throughly wetted, conventional highway marking beads passing a No. 50 sieve were then introduced into the rotating mixer in excess. The mixer was allowed to rotate for approximately 2 min, during which time the small beads completely coated the aggregate. At this point, rotation of the mixer was discontinued, and the materials were poured onto a drying screen through which the excess beads not attaching themselves to the aggregate fell and were recovered for later use. It is envisioned that this process, which is really very simple, could be converted to a continuous process with a minimum of difficulty. Microscopic examination of the coated particles revealed that the beads were encapsulated to just above their center axis and bonded to the aggregate in a very satisfactory manner. The coated aggregate was then allowed to dry for approximately 1 hr and then placed in a bead dispenser. It was found to be free flowing and was then used in preparing test panels. Retroreflection of these coated particles is excellent, and the use of highly refractive glass contributes further to retroreflection.

By using small beads applied to a carrier, there is an opportunity to obtain more area of retroreflectance per dollar invested in glass. Further, using glass of higher refractive index is suggested. The use of a bead-coated carrier or granules is a direct way to obtain reflecting materials of a larger diameter that will protrude up through submerging water films. Since the granules will reflect the color of the binder attaching the beads to the carrier, the color of the binder in which they are imbedded on the pavement will no longer be a controlling factor. Thus, the retroreflecting media could be removed from the white center and lane lines, thereby improving their daytime appearance. Further, there would be the opportunity to place the reflective granules in some of the black, low cost bituminous thermoplastics used to provide contrast stripes and that have physical properties better suited for holding materials of a larger diameter than have conventional paints. Thus, in performance, as darkness approached, the unbeaded white paint stripes would become progressively less visible, but the black contrast stripes would become white because the retroreflected light would be light focusing in the white binder holding the beads to the carrier.

Another method of reflectorizing the black contrast stripes would be to drop on large glass beads of a uniform diameter, a small portion of which have been coated with a water-soluble pigmented binder that would immediately wash off the top of the bead making it retroreflective and a large portion of which have been coated with a water-insoluble pigmented binder which would, with time and abrasion, wear away and become retroreflective.

Reflectors Mounted on Posts

Reflective objects mounted vertically on posts along the roadway are very visible either dry or wet; they find excellent application around curves and when used to mark obstacles. However, they do not offer the advantages of a pavement marking in that, if they are located too close to the edge of the road, they quickly become covered by a surface film. Thus, unless they are periodically cleaned, they become a hazard, with vehicles striking them. They can be used to advantage along a straightaway to give delineation to the general road pattern; however, the guide they provide during periods of precipitation is considerably less efficient than a pavement marking.

DESIGNING THE MARKING SYSTEM FOR ALL-WEATHER VISIBILITY

Using a paint binder of a single thickness with a gradation of bead sizes for general application, irrespective of road surface conditions, fails to give proper return for one's investment in marking materials. Consideration should be given to the texture or profile of the road surface as it relates to retroreflection under wet and dry conditions. Water films on roadways have been determined to be within certain limits. Thus, if a road surface has a profile that is sufficiently smooth to permit applied retroreflective materials to be submerged during periods of precipitation, then such markings cannot be expected to be retroreflective when wet. By the same token, surfaces with sufficient irregularities to raise the retroreflecting materials above the submerging water films can be efficient. Thus, to obtain a system that will give maximum retroreflectance under varying environmental conditions, one should first determine the surface profile of the roadway to be marked. Once this profile has been determined, the marking system yielding the greatest efficiency should then be selected for use.

Pavement Surface Profile

It was concluded that a profile recorder for field use should be a simple, portable, mechanical device that could be handled by one man and record enough length of road to be representative of the area to be marked. Further, it should magnify the vertical displacements of the road surface by a factor of at least 4. Figure 17 is a photograph of an instrument designed and built for obtaining such measurements. In the field, this instrument is placed on the pavement surface to be marked, and the spring-loaded ballpoint stylus is released so that it encounters the paper strip chart. The feeler and stylus carriage is then moved down the frame, thereby recording a magnified profile of the pavement surface. The paper strip chart is then removed, identified, and returned to the office for interpretation. Some typical recordings encountered are shown in Figure 18.

Interpretation of the chart is handled in the following manner. A median line bisecting the recorded curve is drawn so that the area under the curve and above the bisecting line is equal to the area below the bisecting line and the curve. The bisecting line is considered to be the mean surface of the road above which precipitation can find passage to flow away. The area below the bisecting line is considered to provide surface depression storage. Since water films have been measured and found to range from 30 to 40 mils, this height can then be scaled in above the bisecting line, thus indicating the number of protrusions in the surface that will be expected to be exposed and retroreflective during periods of precipitation. If, in a length of 2 ft, there are fewer than 16 protrusions rising 0.015 in. above the scaled-in water depth, then the texture is considered to be smooth. If there are more than 16 protrusions rising 0.015 in. above the scaled in water depth, the texture is considered to be rough.

It is imperative that one record the surface profile of the areas to be marked because the transverse surface profile of a pavement can vary widely. Wheel track areas are often very different from the general surface. Repeated applications of marking materials to a given area can result in a profile also quite different from that of the general surface.

Selection of the Marking System

On a rough surface conventional markings can be employed to give good reflectance in both dry and wet conditions. One exception to the use of conventional markings on a rough surface is the use of beads of a single size matched to the binder thickness to give maximum efficiency. The

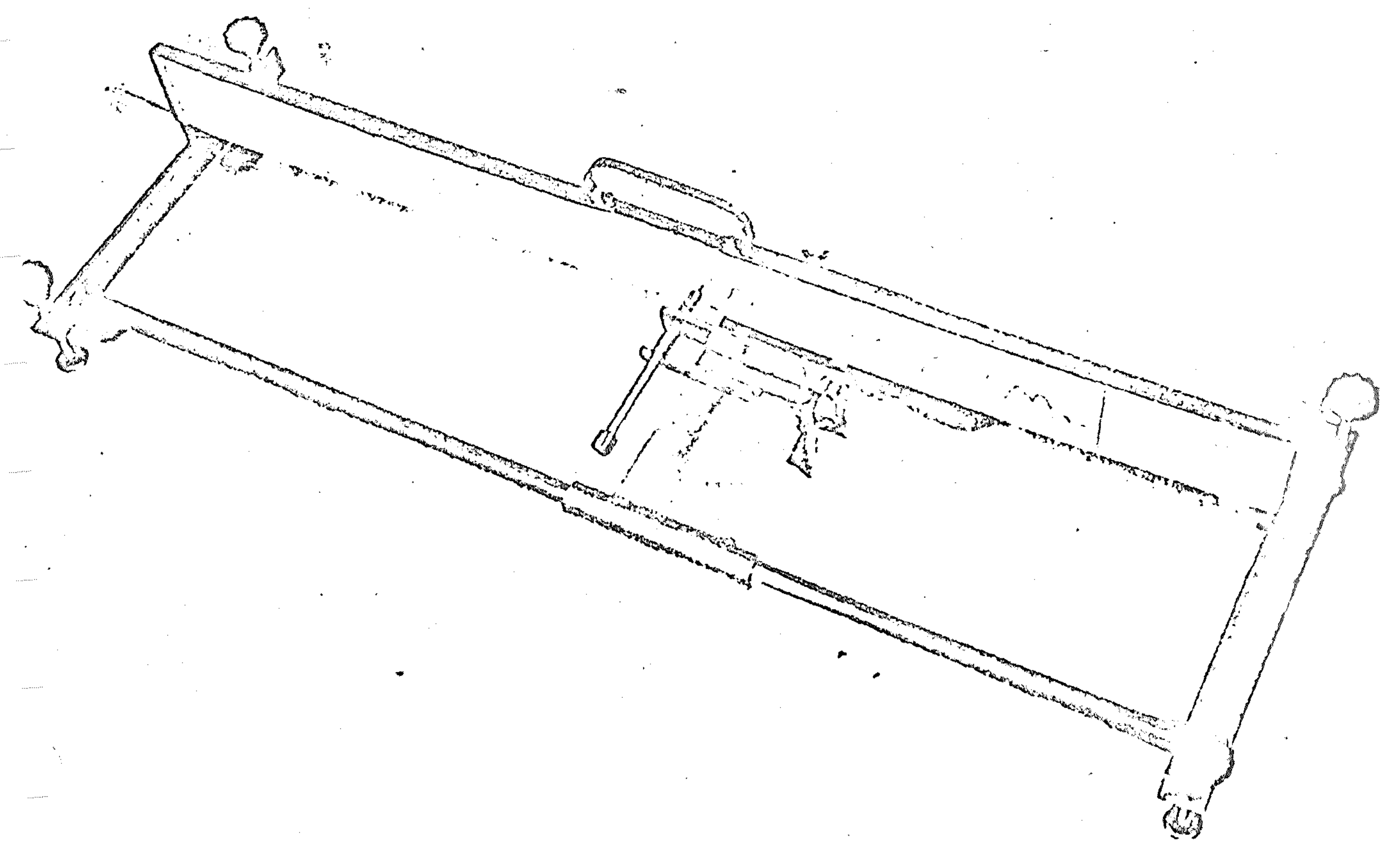


Figure 17. Pavement surface profile recorder.

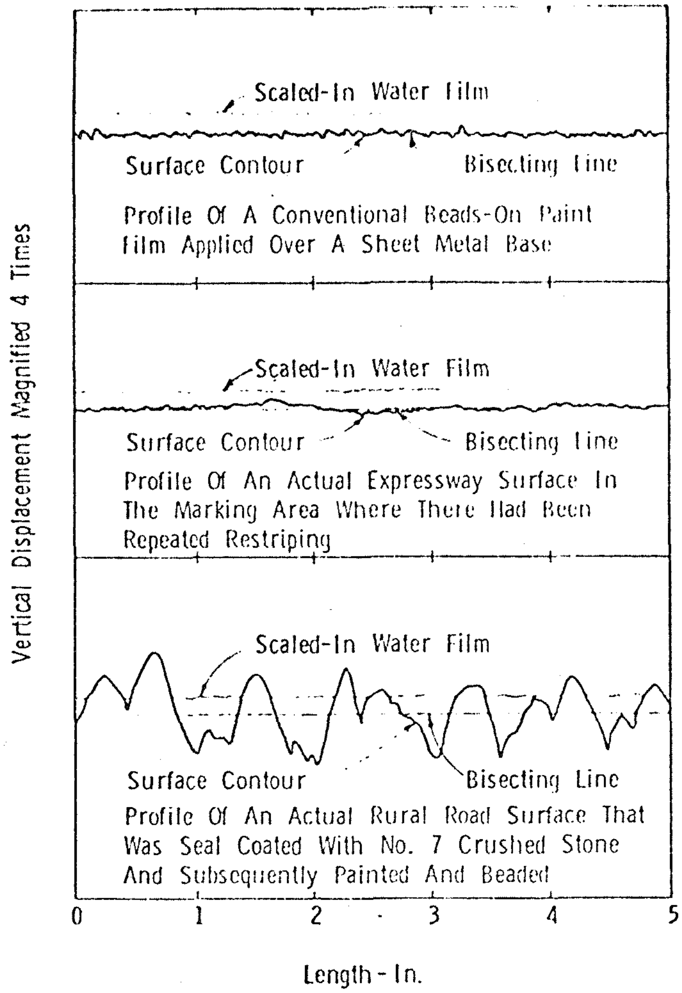


Figure 18. Typical pavement surface profiles.

use of a gradation of beads of various sizes is unattractive, since wearing characteristics are such that the smaller beads have little chance to exhibit their retroreflective capabilities.

When a road surface is either naturally rough or the area to be marked has been given a pretreatment so that it can be classified as having a rough surface, another system with potential would involve the use of a two-coat application procedure: an initial heavy hiding coat of paint is applied and allowed to dry; a second thin binder coat is then applied with a simultaneous dropped-on application of small glass beads of a single size matched to the second coat thickness so as to give optimum reflection efficiency. The advantage of such a procedure would be the use of beads of a smaller diameter with their greater area of reflectance per unit weight of glass. It would have the disadvantage of involving the cost of a second application.

The film thicknesses of marking materials currently applied will sufficiently hide a black bituminous surface. In re-marking operations, where the surface is rough yet light colored (as with some concretes), a thinner binder coat with the smaller beads of single size could, in many instances, be sufficient and offer a savings over the present practice of using one system for all situations. Transverse markings and center, lane, and edge lines are each subject to different and less severe service, respectively, and therefore could be marked accordingly with appropriate savings. The use of raised, reflectorized markings; raised, reflectorized markers in combination with raised, unreflectorized markers; and thin film markings with or without glass beads in combination with raised, reflectorized markers are three systems that can perform effectively on both rough and smooth surfaces.

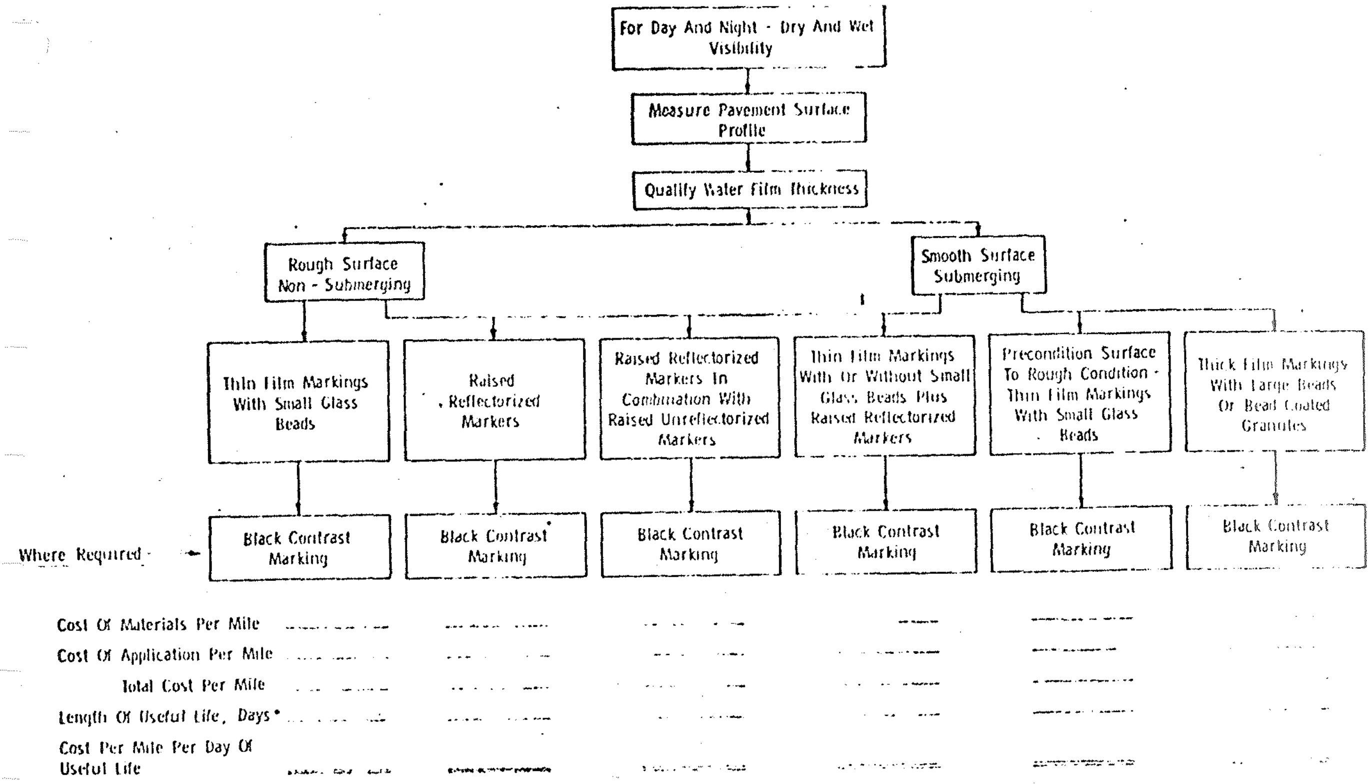
Where a smooth surface is encountered, it is to be expected that the application of conventional paint with beads of standard gradation dropped on will be ineffective during periods of precipitation.

Another method of approaching the smooth surface condition involves preconditioning the area to be marked with an aggregate and then applying a conventional paint with dropped-on beads of a single size matched to the binder thickness to give optimum efficiency. Large beads of a single gradation in a thick binder may also be used in this situation. Since conventional paints do not lend themselves to heavier applications and do not have the power to hold the large beads, which suffer dislodgement under traffic more readily than the small beads, one must look to the thermoplastic and other binder materials being developed. Employing large beads of a single size insures their protrusion through the water films, even under conditions of abrasive wear when the binder is slowly being lost. The use of small beads or a gradation of beads results in the smaller beads being buried in the binder upon application; even after abrasion of the binder, they have insufficient height to protrude above the water films before they are dislodged.

Another solution is to use reflective granules. These are particles of some material, such as an aggregate, that have been coated with an appropriately colored binder and further coated with beads of a single size and small diameter matched to the binder thickness. These granules are then dropped into a second binder, which has been applied to the road and which has sufficient thickness and physical strength to hold them under traffic. Furthermore, use of beads as a coating on granules provides an opportunity to utilize those of a small diameter with their greater retroreflecting area per unit weight of glass than beads of a large diameter.

Comparing Systems

Selecting a system for a given application resolves itself into an effectiveness analysis and must be geared to the conditions encountered in the field. Figure 19 is an example of a flow diagram for comparing systems. It indicates, among other things, that the proper selection of a delineation system involves several variables, each of which must be evaluated and related to one another if maximum benefit is to be derived from the marking materials.



*Institute Of Traffic Engineers Technical Report No. 4 - ASTM Designation D - 713, D - 821, D - 913, D - 1011.

Figure 19. Flow diagram for comparing highway marking systems.

CHAPTER FOUR

APPLICATION OF FINDINGS

DEVELOPMENT AND FIELD TESTING OF AN ADVANCED DAY-AND-NIGHT, DRY-AND-WET MARKER

By considering the various principles that influence the performance of marking materials, it is possible to select one of several methods of improving the delineation of roadways or of employing these principles, and to design additional and improved marking systems. The design of one such additional system was undertaken. In reviewing the previous sections of this report, one finds continued reference to the use of large beads of a single size, stronger binders, and high-speed application techniques. Furthermore, in designing marking systems for all-weather visibility, the use of raised, reflectorized markers finds application on pavements having both smooth and rough surfaces. Thus, developing a system incorporating the combined features of the ability to be applied like a paint but perform like raised, reflectorized markers was undertaken. To do this, it was necessary to select a reflectorizing medium and a binder and then to field test the combination.

For a reflectorizing medium, glass beads were chosen because of their simplicity and low cost. From a mechanical standpoint and for random application a material having a spherical shape as opposed to an irregular shape is ideal for transmitting an imposed load. A glass bead should rise at least 60 mils above any water film encountered during periods of precipitation. Based on a 40-mil water film and a 20-mil imbedment of a bead over its equator for binding and proper retroreflectance, a bead radius of 120 mils results; thus, a glass bead having a diameter of 240 mils or approximately 0.25 in. is needed. A commercially available source of glass beads of this size proved to be limited to one company. It was found that manufacturers of glass beads for highway marking produced a mixed gradation ranging from 10 to 200 mesh, and that commercial manufacturers of marbles produced these at a diameter down to 0.375 in.

The only glass beads of 0.25 in. diameter that could be located were from the Industrial Components Department of Corning Glass Works. Unfortunately, these beads were made of glass with a low refractive index, whereas glass beads with a high refractive index would have been preferable. However, it was desired to proceed with the development work using the glass beads with a diameter of 0.25 in. and a low refractive index and at the same time to initiate contacts with several manufacturers for the production of some beads of this size with a high refractive index. Bead-coated granules could have been used effectively had they been available or had there been time to prepare them. The use of beads of single size with a large diameter has the potential of providing a reflective medium that would have better self-cleaning characteristics under precipitation and the action of vehicle tires than gradations of small beads or bead-coated granules.

As a high-strength, thick-film binder for beads of a large diameter, conventional paint materials have the major limitations of less strength, longer drying time, and less adhesion compared with the plastic or resin materials of both the thermosetting and thermoplastic types. Outstanding among the resin materials for durability, curing time, and adhesion are the epoxy materials. They are widely used as an adhesive for applying factory-made raised, reflectorized markers. Although they were selected for use in this effort, some of the other resin types could have been used and deserve more attention because of their generally lower cost. To give the epoxy color as well as body so that it would not be too fluid to hold a thick film, a filler and a pigment were required. Titanium calcium was used as both a filler and a pigment. Other less expensive and physically stronger fillers are readily available.

So as to gain acceptance and lower the cost of raised, reflectorized markers, it is desirable that they be applied at speeds approaching those at which conventional marking paints are applied. The practice of making a raised, reflectorized marker in a plant at one site and applying it by hand at another site appeared less desirable than the concept of physically making and applying a raised, reflectorized marker in one operation at the same site at speeds approaching those employed for applying paint. The expense of machinery of sufficient capability to perform this function was beyond the budgetary limits of the program at that stage.

TABLE 4

COMPOSITION AND COST OF RAW MATERIALS USED IN REFLECTORIZED MARKERS ON ROADS AT SOUTHWEST RESEARCH INSTITUTE, 1966

WEIGHT PER UNIT (G)	MATERIAL	APPROXIMATE COST, ($/UNIT)
16	Shell Epon 828 epoxy resin	0.0432
16	Ti Cal pigment	0.0035
4	Shell epoxy curing agent U	0.0124
7	19 glass beads, 0.25 in. diameter 1.5 RI	0.0100
	Total cost	0.0691

Initial experimentation was conducted by making and placing a number of markers on Southwest Research Institute roads. On June 16, 1966, a half-mile section of Culebra Road, which is a county-owned, asphaltic concrete road bordering Southwest Research Institute, was selected for marking by the developed technique. Reflectorized markers made from a pigmented epoxy and glass beads with a diameter of 0.25 in. and a low refractive index were applied at 40-ft intervals at the center point of the unpainted space between the existing 15-ft painted skip stripes. As the raised, reflectorized markers were being

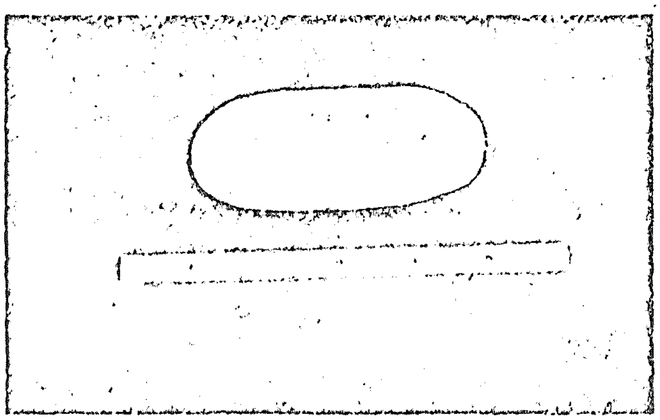


Figure 20. Experimental highway marker.

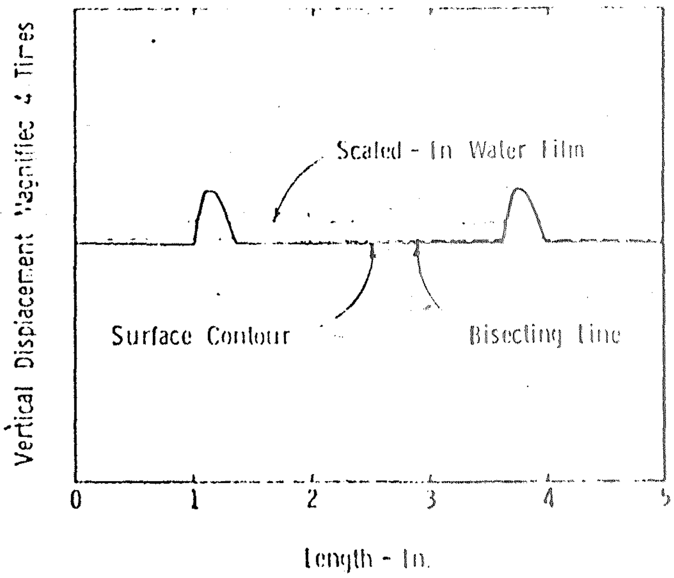


Figure 21. Surface profile of experimental highway marker.

applied, the white center skip stripes were repainted. Table 4 gives the composition and approximate cost of raw materials for the raised, reflectorized markers.

Physical placement of the markers involved premixing the pigment and the resin with a hand-drill mixer. The curing agent was then added and mixed with the resin. The mixture was then poured onto the road surface in a configuration approximately 4 × 2 × 0.145 in. A small perforated plate holding 19 glass beads 0.25-in. in diameter in a desired pattern was then placed over the freshly applied resin material and by a tripping mechanism made to fall into the resin; the beads then sank by gravity to the point where they were imbedded to approximately 60 percent of their vertical height. *Figure 20* is a photograph of one of the experimental markers. The curing time for the resin system was approximately 15 min, after which the markers were released to accept traffic. This installation was observed closely over the summer and through the fall, in the wet and dry conditions, which occurred both naturally and were created artificially, down through the end of the project; the final inspection occurred on December 15, 1966.

The physical performance of the raised, reflectorized markers was better than anticipated. A surface profile of one of these markers is shown in Figure 21. Protrusion of the reflective elements of the glass beads 0.25 in. in diameter is shown to be sufficient to resist submergence by anticipated water films. The markers' ability to be retroreflective when subjected to natural and artificial precipitation was excellent; however, it was unfortunate that glass beads of a high refractive index could not have been located since their use would have materially improved the brightness of the individual markers. Physical damage to the large diameter glass beads was almost nonexistent except that several of the markers lost one or two beads where the resin began to react and set and became too viscous to allow the bead to settle and imbed itself over its horizontal axis. The only major physical damage to the markers occurred in two places where someone employed a blunt instrument, drove it into the pavement, and broke out sections of two markers for souvenirs. The paint stripes at this location had deteriorated to such an extent that, on December 1, they were repainted.

Because of the low vertical height of the developed markers, they should be less subject to snowplow damage and not require physical removal before resurfacing operations.

CHAPTER FIVE

CONCLUSIONS

So as to improve center, lane, and edge lines as well as the many other pavement markings used in delineation of roadways in the wet and dry condition, the following conclusions are made:

1. A systematic approach to marking pavements is needed wherein one obtains a pavement surface profile of the surface to be marked, qualifies the water film thicknesses to be encountered, and then selects one of several marking systems that will perform under the imposed conditions and provide the lowest cost per mile per day of useful life.
2. Only under very unusual circumstances, such as when a road surface is extremely rough or when the area to be marked has been pretreated to present a very rough surface, can conventional paint binders, reflectorized with the current bead gradations, be expected to perform when wet.
3. Retroreflective materials can perform satisfactorily, even when wet, so long as they are not covered by a layer of water. Raised, reflectorized markers perform in this manner and are very effective. The use of glass beads of a larger diameter or bead-coated granules in thicker binders or improved binders, such as some of the thermoplastic or thermosetting resins that have sufficient mechanical properties to hold these materials under traffic, is another attractive approach to this problem.
4. Incorporation or placement of retroreflective materials other than in or on surface film markings such as paint improves the daytime visibility and appearance of surface film markings.
5. Great benefits are seen from the use of beads that are essentially the same diameter, the diameter selected being the one that will result in the beads being imbedded in the binder to 55 to 65 percent of their vertical height.
6. The idea of producing waterproofed or water repellent glass beads is an excellent concept. Unfortunately, the silicone and other available treatments appear to be so short lived in the field that they are of little practical significance.
7. The use of glass beads of a high refractive index and the use of larger quantities of glass per unit of stripe offer improvements in the field, however, it

would appear that, in the immediate future, greater dividends would accrue from the better utilization of glass beads having a low refractive index and costing less through improved bead gradation specifications and application techniques.

8. Marking authorities should consider adding equipment, either separate or complementary, to their present marking machines that will allow raised, reflectorized markers to be made at high speed in one operation at the point of application along the lines of the system developed in this program and described in this report.

CHAPTER SIX

SUGGESTED RESEARCH

It is recommended that future attention be given to the following points:

1. An analysis of the precipitation by areas as it relates to water films on various types of pavement surfaces and slopes to establish detailed design criteria for water film depths.
2. A qualification of rainfall intensity wherein the light scattering effect is sufficient to influence the ability of retroreflective materials to receive and return light.
3. The development of an inexpensive night visibility meter that can be used to evaluate pavement markings in both the dry and wet condition.
4. The development of a system for qualifying the point at which the contrast of a pavement-marking material and the road surface is insufficient and a contrast stripe is needed.
5. The development of thicker film and more durable and less expensive marking materials.
6. A study of raised markers in terms of their present and future use both separately and in conjunction with surface-film markings and their relation to snow removal operations from the standpoint of determining if the marking system should be designed to accommodate the snow removal equipment or if the snow removal equipment should be designed to accommodate the marking system.
7. The further development of the concept of both making and applying on site raised, reflectorized markers.

REFERENCES

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3. IZZARD, C. F., "The Surface Profile of Overland Flow." *Trans. Amer. Geophys. U.*, pp. 959–968 (1944).
4. POCOCK, B. W., and RHODES, C. C., "Principles of Glass Bead Reflectorization." *HRB Bull. 57* (1952) pp. 32–48.
5. "Tips on a Tire Market." *Chem. Week*, p. 76 (Dec. 17, 1966).

APPENDIX E

FAA Contact Reports and References

-CT BY: PHONE CALL ( ) TO BSCP (X) FROM BSCP | VISITS ( ) VISIT TO BSCP ( ) VISIT TO ________ | OTHER ( ) ________ ________

-F CONTACT: 5/10/71 GROUP: BSCP/TAG DATE OF REPORT: ________

-ACT
-ES AND POSITIONS: Fred Horne
Airport Pavement R&D

-PANY OR AGENCY: FAA/DOT-R&D Office
-RESS: ________
PHONE: 426-8427
-P PERSONNEL: H.N. Cantor

-CONTACT ORIGINATED (please be specific)

H. Miller (DOD-Army) recommended contact

-BJECT: Procure copies of Miller's DOD/FAA Reports
-PORT:

- Skid resistance quality paint (aircraft runway problems); other considerations secondary

- Belvoir (epoxy lacquer, ground glass/aluminum oxide)

- Reports are preliminary

- As responsible for the Atlantic City work/get their reports from NTIS (visibility)

(if required, use additional paper)

-ION TO BE TAKEN:

He will send copies of their (Belvoir) reports Recd report

BY: Horne DATE: ASAP

-STRIBUTION: (please mark each copy)

Chrono File ( ) Shilling ( ) Cantor ( ) Johnston
) File: ________ ( ) Weeks ( ) Wilson ( ) ICMA
( ) NASA/OTU

REPORT BY:

N70-37021# ISSUE 20 PAGE 3707 CATEGORY 11
FAA-RD-70-40 FAA-NA-70-21 00/00/00 UNCLASSIFIED DOCUMENT
Simulation of a continuous runway centerline marking Interim report
(Simulation of continuous runway centerline marking)
A/BROWN, G. S.; B/SULZER, R. L.
NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER, ATLANTIC CITY, N. J. AVAIL.NTIS
/*ALL-WEATHER AIR NAVIGATION/*FLIGHT SIMULATION/*LANDING AIDS/*MARKING/*RUNWAYS/ AIRPORTS/ LOW VISIBILITY

N70-36858 European Organization for Nuclear Research, Geneva (Switzerland).
POSITIONING OF THE CERN INTERSECTING STORAGE RINGS: THE GEODETIC APPROACH
J. Gervaise 30 Jun. 1970 31 p refs Presented at the Journee d'Inform. sur la Topometrie de Haute Precision, Lyon, 13 Feb. 1970
(CERN-70-18) Copyright. Avail: Issuing Activity

The intersecting storage rings (ISR) consist of two concentric rings of magnets in which protons travel in opposite directions. The magnets are housed in a circular underground tunnel and are interlaced as to intersect at eight points where the beams can be made to collide. The problem of positioning the ISR components is approached geodetically; ISR geometry, laying out, and linking up with the 28 GeV accelerator are discussed. ISR metrology, based solely on distance measurements, is discussed, and a comparative analysis of the geometry of the 28 GeV PS is made with that of the ISR. The method to be used for aligning the 800 MeV booster synchrotron is described. An approach is made to the metrology to use for the future 300 GeV synchrotron. P.A.B.

N70-36893*# Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena. Environmental Sciences Div.
SPACE SIMULATORS AND FACILITY ENGINEERING
In its Space Programs Sum. No. 37-62, Vol. 3 30 Apr. 1970 p 223-227 (See N70-36876 20-34)
Copyright. Avail: CFSTI CSCL 14B

The simulation of cosmic radiation, solar flares, solar winds, and Jovian radiation belts is studied for accelerated testing of outer planet missions. The operating conditions of accelerated testing, equivalent to a 10-year mission are tabulated. F.O.S.

N70-36909# Hovey-Sores (Ottawa).
AN ANALYSIS OF AIRPORT SNOW REMOVAL AND ICE CONTROL Interim Report
D. J. Tighe, L. A. Garland, and J. C. Cairo Apr. 1970 118 p refs
(Contract FA-69-WAI-149)
(FAA-RD-70-38) Avail: CFSTI

An approach is described using modelling techniques by which airport snow removal and ice control systems may be evaluated on a cost effectiveness basis, taking into account (1) airport type, size, and structure; (2) incidence of snow and/or icing conditions; and (3) volume and type of air traffic. Technical characteristics of the equipment and systems are also discussed. Conclusions and recommendations are enumerated for factors influencing system design, current snow removal and ice control practices, and future research in airport snow removal and ice control. Author

primary electrode. Examples ... means are given, with and without the use of a tease wire. P.A.B.

N70-36965# Technion - Israel Inst. of Tech., Haifa. Aeronautical Research Center.
THE IIT 40cm x 50cm INTERMITTENT, SINGLE JACK, FLEXIBLE NOZZLE SUPERSONIC WIND TUNNEL-CALIBRATION AT MACH NUMBERS 1.5 TO 3.0
I. Etsion, J. Rom, and M. Salomom Apr. 1970 22 p refs Presented at 33d Semiann. Meeting of the Supersonic Tunnel Assoc., El-Segundo, Calif., 7 - 8 May 1970
(TAE-110) Avail: CFSTI

A test program was conducted to calibrate the test region of the 40cm × 50cm single jack, flexible nozzle supersonic wind tunnel. A general description of the wind tunnel as well as results of the calibration at nominal Mach numbers of 1.5, 2.0, 2.5 and 3.0 are presented. The maximum Mach number variation was + or − 0.01 along the centerline of the sidewall and also + or − 0.01 in the test cross section area for all these Mach numbers. Author

N70-37016# Rome Univ. (Italy). Scuola di Ingegneria Aerospaziale.
DESIGN CRITERIA AND CHARACTERISTICS OF THE BLOWDOWN WIND TUNNELS OF THE CENTRO RICERCHE AEROSPAZIALI [CRITERI DI PROGETTO E CARATTERISTICHE DEGLI IMPIANTI AERODINAMICI INTERMITTENTI DEL CENTRO RICERCHE AEROSPAZIALI]
Ugo Ponzi Jun. 1969 46 p refs In ITALIAN; ENGLISH summary *Its* ATTI del Centro Ric. Aerospaziali No. 22
Avail: CFSTI

After general consideration of blowdown wind tunnel operation, the basic criteria and methods for their design and for the calculation of their characteristics are reviewed. The three main elements of these facilities, the air storage, vacuum, and thermal capacity heating systems, are discussed and the blowdown wind tunnels of the Centro Ricerche Aerospaziali (CRA) are described. Author (ESRO)

X N70-37021# National Aviation Facilities Experimental Center, Atlantic City, N.J.
SIMULATION OF A CONTINUOUS RUNWAY CENTERLINE MARKING Interim Report
Guy S. Brown and Richard L. Sulzer Aug. 1970 27 p
(FAA-RD-70-40, FAA-NA-70-21) Avail: CFSTI

A simulation study was conducted to compare a continuous runway paint marking with the U.S. standard broken centerline stripe under low-visibility conditions. Overall results showed no strong preference for the guidance value of the continuous centerline. Despite this, the most experienced pilots reported advantages in the continuous mark in that it could be seen farther in reduced

recd p. 3708

visibility and gave slightly better guidance; however, they indicated only a moderate strength of preference. Highlighting one advantage of an interrupted centerline marking, pilots stated the need for speed information. A strong chance was noted that the location of the markings could be confused if the present standard system were revised by exchanging the locations of interrupted and continuous markings. Pilots also reported that VFR as well as instrument runways need to have a common marking. The preferences and comments of the most experienced subject pilots suggest that the present centerline could be improved for low-visibility operations by reducing the length of the gap, without giving up the benefits of speed information, while retaining the broken centerline concept.
Author

N70-37035# Battelle-Northwest, Richland, Wash. Pacific Northwest Lab.
CAPABILITY OF A TYPICAL MATERIAL BALANCE ACCOUNTING SYSTEM FOR A CHEMICAL PROCESSING PLANT
R. A. Schneider and D. P. Granquist May 1970 35 p refs
(Contract AT(45-1)-1830)
(BNWL-1384) Avail: CFSTI

The development of two basic models, a capability model and a performance model, for a chemical processing facility is discussed. The capability model represents the best performance (the smallest error) that the measurement system is theoretically capable of achieving in an operating environment. The performance model represents that expected in practice from a high quality measurement system. A Purex-type flowsheet was assumed for a plant operating on a clean-plant-to-clean-plant basis. It was also assumed that a campaign consists of 40 tons of irradiated low-enriched uranium containing 10,000 g/ton of plutonium.
NSA

N70-37041# California Univ., Berkeley. Lawrence Radiation Lab.
ENGINEERING STUDY OF RADIOLOGICAL FIRE PREVENTION AT LAWRENCE RADIATION LABORATORY, BERKELEY, CALIFORNIA
Jensen Young Jan. 1970 34 p refs Presented at the Am. Ind. Hyg. Assoc. Conf., Detroit Sponsored by AEC
(UCRL-19465) Avail: CFSTI

Some of the engineering steps taken at the Lawrence Radiation Laboratory, Berkeley, California, to reduce the hazards of fire in radioisotope areas are discussed and evaluated. These include the selection of fire-retardant materials for enclosures to meet the variable and unpredictable demands of researchers, fire tests on enclosure components, modification and testing of a fire extinguisher for glove boxes, evaluation of radioisotope storage areas, and a critical look at mechanical ventilation in a radiological fire. NSA

N70-37122# California Univ., Livermore. Lawrence Radiation Lab.
A PULSED DIVERTER AND GUIDE FIELD FOR THE SUPERCONDUCTING LEVITRON
E. J. Lauer 13 Feb. 1970 9 p Sponsored by AEC
(UCRL-50807) Avail: CFSTI

The design of a pulsed diverter and guide field for the Superconducting Levitron is optimized so that a maximum area at the remote end of the guide field coil is bounded by magnetic flux lines which lie on useful flux surfaces in the Levitron. The guide field is compensated for the fringe field of the Levitron. Flux lines are followed using a numerical calculation. For torus currents corresponding to 300 kA in the floating ring, a guide solenoid current producing about 15 kG results in the above area being about 2 or 3 cm by 4 or 5 cm. Author (NSA)

N70-37186*# General Electric Co., Cincinnati, Ohio.
ADVANCED REFRACTORY ALLOY CORROSION LOOP PROGRAM Quarterly Progress Report, 15 Jan. 1970 – 15 Apr. 1970
R. W. Harrison and J. P. Smith 11 May 1970 37 p refs
(Contract NAS3-6474)
(NASA-CR-72739; GESP-491; QPR-20) Avail: CFSTI CSCL 11F

The T-111 Rankine system corrosion test loop successfully completed the planned 10,000 hours of continuous operation. The alkali metal was drained from the loop and preparation for posttest evaluation was initiated. Visual examination of the loop showed it to be in excellent condition. The 1900 F lithium loop achieved test conditions on January 31, 1970 and has accumulated 1725 test hours of operation. Two ASTAR 811C potassium reflux capsules successfully completed 5000 hours of testing. One of the capsules was opened and prepared for posttest evaluation. Author

N70-37337# Bolt, Beranek, and Newman, Inc., Cambridge, Mass.
AIRCRAFT NOISE AND AIRPORT NEIGHBORS: A STUDY OF LOGAN INTERNATIONAL AIRPORT
Peter A. Franken and David Standley Mar. 1970 178 p refs
(Contract DOT-OS-A9-009)
(PB-190118; DOT/HUD-IANAP-70-1) Avail: CFSTI CSCL 01E

The report describes a study of means for providing relief from aircraft noise annoyance to residents of the vicinity of Logan International Airport, Boston, Massachusetts. The noise exposure situations in 1967 and 1975 are described in terms of such measures as land area, populations, schools, and hospitals affected. Operational noise abatement procedures considered include flight track changes, preferential runway systems, runway threshold shifts, aircraft type restrictions, power cutbacks, and schedule restrictions. Nonoperational abatement procedures considered include land use management and redevelopment, and acoustic insulation. The report also describes the utilization of abatement procedures at other major airports, and presents a generalization of the approaches developed in a form suitable for use by other airport authorities. Author (USGRDR)

N70-37424*# National Aeronautics and Space Administration. Goddard Space Flight Center, Greenbelt, Md.
THE EARTH-MOON TEST RANGE
Robert C. Wigand Jun. 1970 24 p Proposed for presentation at 1st Western Space Congr., Santa Maria, Calif., 27–29 Oct. 1970
(NASA-TM-X-65316; X-834-70-239) Avail: CFSTI CSCL 14B

Recent developments in technology, including the demonstrated capability to emplace and operate equipment packages on the lunar surface, have established the feasibility of an Earth-Moon Test Range. The Range will investigate the characteristics of the Earth's macroenvironment in cislunar space and will develop new techniques for the use of electromagnetic signals. Advantages of lunar distance in experimental control, perspective, and calibration, as well as the benefits of initiating a Range program are discussed.
Author

N70-37528*# National Aeronautics and Space Administration. Marshall Space Flight Center, Huntsville, Ala.
DEVELOPMENT AND TESTING OF THE LUNAR GRAVITY AND EARTH ORBITAL SIMULATOR (PARALLELOGRAM)
H. T. Blaise 12 Sep. 1969 19 p
(NASA-TM-X-53892; MSFC-IN-ME-68-13) Avail: CFSTI CSCL 14B

An account of work accomplished in the development and testing of the lunar gravity and earth orbital simulator or parallelogram (L/G and E/O) is given. The L/G and E/O was developed and tested from contract specifications. Included in the report are events and happenings during development, proof testing, irregularities of achieving balance of the L/G and E/O and the remedies used to correct the faults. Author

X N65-33425# ISSUE 21 PAGE 3604 CATEGORY 11
RD-65-45 65/04/00 UNCLASSIFIED DOCUMENT
Development of runway marking machine and cold-w
ater paint for airport surface marking final repor
t
(Runway marking machine and cold water paint for
airport surface marking)
A/TWICHELL, N. H.
FEDERAL AVIATION AGENCY, ATLANTIC CITY, N. J.
(EXPERIMENTATION DIV.)
APR. 1965 30 P
/*AIRPORT/*PAINT/*RUNWAY/ APPLICATION/ AVAILABI
LITY/ COLD WATER/ DEVELOPMENT/ DRYING/ MACHINE/ MA
RKER/ MOBILITY/ PATTERN/ SPEED/ SPRAY/ SURFACE/ UN
IT

[1965] 20 p Presented at the Tech. Meeting and Equipment Exposition at the Inst. of Environ. Sci., 21-23 Apr. 1965
(Contract NAS1-1918(c))
(NASA-CR-64769) CFSTI: HC $1.00/MF $0.50 CSCL 14A

Described is the construction and operation of an ultra-high vacuum environmental chamber with cryogenic walls at liquid helium temperatures. This chamber attains low pressures, similar to those in space, by a combination of diffusion pumping and cryogenic pumping. Schematics of the vacuum facility and the refrigerator are shown, and a detailed discussion of each of the components of the vacuum system is presented. G.G.

N65-33349# Lockheed Missiles and Space Co., Sunnyvale, Calif.
GEMINI AGENA TARGET VEHICLE Reports Bibliography, 30 Jun. 1964
1 Sep. 1964 16 p
(Contract AF 04(695)-129)
(LMSC-A605144; AD-462886)

A bibliography on the Gemini Agena Target Vehicle is presented. It pertains to reports published prior to July 1964. Topics covered include communications and control systems, flight planning, human factors, various engineering manuals, presentations and briefing aids, product assurance, and propulsion system. J.M.D.

X N65-33425# Federal Aviation Agency, Atlantic City, N. J. Experimentation Div.
DEVELOPMENT OF RUNWAY MARKING MACHINE AND COLD-WATER PAINT FOR AIRPORT SURFACE MARKING Final Report
Nathaniel H. Twichell Apr. 1965 30 p
(RD-65-45)

A low-cost mobile spray unit was developed for applying experimental marking patterns on runway and taxiway surfaces. Speed of application and drying were essential since runway availability was critical; therefore, a cold-water paint was developed for use with the spray unit. The prototype paint spraying device was assembled from readily available stock components and tested. The cold-water airport paint, developed concurrently, proved compatible with the spray unit and possessed the required ease of handling and application qualities. Results of this prototype unit testing indicate that a mobile paint spraying device, similar to the type developed, would be well-suited to the task of marking runway and taxiway surfaces, particularly where frequent repainting of touchdown areas is necessary. Author

N65-33443# Los Alamos Scientific Lab., N. Mex.
AN INERT ATMOSPHERE ENCLOSURE FOR THE PREPARATION OF SAMPLES PRIOR TO THE DETERMINATION OF OXYGEN

in place. Nitrogen and carbon dioxide also are removed effectively by the purification system. Relative efficiencies of anhydrous magnesium perchlorate and molecular sieve as desiccants, and of heated copper and uranium turnings as getters, were investigated. A device is described that prevents atmospheric contamination of samples during transfer from the enclosure to an apparatus for determining oxygen. Author

N65-33451# Stanford Univ., Calif.
TWO-MILE ACCELERATOR PROJECT Quarterly Status Report, 1 Jan.–31 Mar. 1965
Jun. 1965 102 p refs
(Contracts AT(04-3)-400; AT(04-3)-515)
(SLAC-45) CFSTI: $4.00

Details on the construction of a two-mile long linear electron accelerator, and site preparation, buildings, utilities, and associated work are reported. Among the areas discussed are plant engineering, systems engineering and installations, accelerator physics, instrumentation, heavy electronics, mechanical design and fabrication, klystron studies, beam switchyard, and pre-operations research and development. C.T.C.

12 FLUID MECHANICS

Includes boundary-layer flow; compressible flow; gas dynamics; hydrodynamics; and turbulence. For related information see also: 01 Aerodynamics; and 33 Thermodynamics and Combustion.

N65-32439* Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena.
AXISYMMETRIC STEADY FLOW OF A SWIRLING COMPRESSIBLE FLUID THROUGH A CONVERGENT-DIVERGENT NOZZLE WITHOUT EXTERNAL HEAT TRANSFER
P. F. Massier *In its* Space Programs Sum. No. 37-33, Vol. IV 30 Jun. 1965 p 133–141 refs (See N65-32410 21-11)
CFSTI: HC $7.00/MF $1.75

Ambient temperature swirling flows through nozzles was investigated in conjunction with ionized gas-flow experiments. A combination of analysis and experimental results indicate that the swirling flow through a nozzle consists of essentially two types of swirling regions. A core exists in which the tangential velocity distribution is approximately that of solid body rotation. In the outer annulus the tangential velocity distribution is more nearly that of a potential vortex. A consequence of the analysis based on the simplifying assumptions is that the tangential component of the velocity depends only on the radial coordinate and not on the axial coordinate. Hence the expansion process results in an increase of only the axial component of the velocity. For the amount of swirl injected in

N67-10424# ISSUE 1 PAGE 57 CATEGORY 11 RD-66-37 66/05/00 UNCLASSIFIED DOCUMENT
A configuration design concept for distance coded marking of category II and IIIA RUNWAYS Final report
(Design concept for distance coded runway markings)
A/BROWN, G. S.; B/MC KELVEY, R. K.
FEDERAL AVIATION AGENCY, ATLANTIC CITY, N. J. (TEST AND EVALUATION DIV.)
MAY 1966 138 P REFS
/*INSTRUMENT APPROACH/*RUNWAY/*SYSTEMS DESIGN/ AID/ APPROACH/ CODE/ CONCEPT/ DEPTH/ DESIGN/ DISTANCE/ INSTRUMENT/ LANDING/ MARKER/ PERCEPTION/ SYSTEM

combustion experiments to be carried out ... the gas-flow is also possible and a high speed camera is to be used to take Schlieren photographs of the flow. An indication of measurements to be taken is also given. Author

N67-10174*# University of Southern Calif., Los Angeles. Electronic Sciences Lab.
MANUAL CONTROL DATA ACQUISITION FACILITY
M. J. Merritt and S. H. Shaar *In its* Res. on New Tech. for the Analysis of Manual Control Systems 15 Jun. 1966 p 2-3 (See N67-10173 01-05) CFSTI: HC $1.00/MF $0.50

Development of an experimental station for studies of multiple input manual tracking control tasks continued. A manual control stick was designed and mounted on the newly installed pilot's seat. Cables were fabricated to connect the analog computer patchboard to the display devices, control sticks, eye position transducer, FM tapy recorder, and communication system. The following digital computer programs were written to support the facility: 7X sample, 7X dump, scale factor, signal distribution function, and the system routines of D load and D dump. R.LI.

N67-10311# Army Cold Regions Research and Engineering Lab., Hanover, N. H.
PERFORMANCE STUDY OF THE DEWLINE ICE CAP STATIONS GREENLAND, 1963
S. C. Reed May 1966 30 p refs
(CRREL-SR-72; AD-638136) CFSTI: HC $2.00/MF $0.50

To study the performance of the DEWline ice cap stations, the following semiannual observations are made: footing elevation and settlement, horizontal angle measurements to indicate lateral movement of the structure, measurement of vertical movement in the sewage disposal and fuel storage systems, and measurement of snow temperature, accumulation, and density. The 1963 observations indicate that in general the structures and utilities are performing as predicted. Author (TAB)

N67-10344# Federal Aviation Agency, Atlantic City, N. J. Test and Evaluation Div.
TESTING OF MASKED LAMPS IN TAXIWAY EDGE LIGHTS Final Report
Cecil B. Phillips Jul. 1966 17 p refs
(RD-66-44; AD 638492) CFSTI: HC $1.00/MF $0.50

Technical tests were performed to investigate the use of masked lamps in taxiway edge lights. These lamps were tested to determine if there were advantages in their use over the ones now being used. The masked lamps were superior for use on the straight portions of the taxiway and on curves where at least three lamps were visible. They were also superior in that they reduced off taxiway light to a minimum. Author (TAB)

N67-10349# Naval Ammunition Depot, Crane, Ind.
EXPERIMENTAL HIGH INTENSITY FLARE SYSTEMS: DESIGN AND TESTS OF
John F. Wildridge Aug. 1966 119 p refs
(RDTR-75; AD 638490) CFSTI: HC $4.00/MF $0.75

1966 Aug.
Natl. Obs. Sponsored by NSF

Progress on the engineering development, ... construction, and improvement of the Cerro Tololo Inter-American Observatory, La Serena, Chile is reported. Activities at the Kitt Peak National Observatory, Tuscon, Arizona are also included. Observations with Kitt Peak's 84-inch, 36-inch, and 16-inch telescopes; the development of Ritchey-Chretien correctors for the 84-inch and 36-inch telescopes; the use of computer programs to control observing programs; work on the 82-inch quartz heliostat flat; and a spectroscopic study of water vapor on Venus are discussed. R.N.A.

X **N67-10424#** Federal Aviation Agency, Atlantic City, N. J. Test and Evaluation Div.
A CONFIGURATION DESIGN CONCEPT FOR DISTANCE CODED MARKING OF CATEGORY II AND IIIA RUNWAYS Final Report
Robert K. Mc Kelvey and Guy S. Brown May 1966 138 p refs
(RD-66-37)

Eight experiments were conducted to provide a configurational design concept for a system of distance coded runway marking geared particularly to the support of landing and take-off operations bright daylight contact fogs (fog extending to the surface—no ceiling). Among other criteria the system must meet are distance coding of a bidirectional runway, compatibility with runway lighting, and resistance to loss of configurational integrity through operational wear. A symbolic distance indicating system was regarded as having demonstrated the greatest potential for meeting the full array of design objectives and is recommended for service test and evaluation. Author

N67-10626# Stanford Univ., Calif. Stanford Linear Accelerator Center.
MAGNETIC FIELD EFFECTS IN HYDROGEN THYRATRONS
Robert W. Bradford May 1966 13 p Presented at the 9th Modulator Symp., Fort Monmouth, N. J., 11-12 May 1966
(Contract AT(04-3)-400)
(SLAC-193; CONF-660528-4) CFSTI: HC $1.00/MF $0.50

The use of weak magnetic fields to improve the performance of hydrogen thyratrons (higher peak and average power levels, tighter anode delay-time stability, higher anode hold-off voltages, and faster repetition rates) is discussed. NSA

N67-10632# Texas A&M Univ., College Station.
THE TEXAS A AND M VARIABLE ENERGY: PROGRESS AND STATUS, JANUARY 1966
W. A. Mc Farlin, J. A. Mc Intyre, M. A. Nowak, M. N. June, and L. B. Hardeman [1966] 4 p Presented at the Meeting of the Soc. of Appl. Spectry., Chicago
(Contract AT(40-1)-3398)
(ORO-3398-4; CONF-660611-2) CFSTI: HC $1.00/MF $0.50

N67-17960# ISSUE 7 PAGE 1061 CATEGORY 11 F
FAA-RD-66-71 06/12/66 UNCLASSIFIED DOCUMENT
Testing of reflective markers for indicating the threshold and centerline of runways for small airports Interim report
(Feasibility of retroreflective markers for improving runway threshold and centerline identification at small airports)
A/PHILLIPS, C. B.; A/TWICHELL, N. H.
FEDERAL AVIATION AGENCY, ATLANTIC CITY, N. J. (TEST AND EVALUATION DIV.)
DEC. 1966 28 P
/*AIRPORT LIGHT/*LANDING AID/*RUNWAY LIGHT/ ACRYLIC/ AID/ AIRPORT/ CENTER/ COST/ FEASIBILITY/ FLIGHT/ IDENTIFICATION/ INSTALLATION/ LANDING/ LIGHT/ LINE/ MAINTENANCE/ MARKER/ NIGHT/ RETROREFLECTION/ RUNWAY/ TAKEOFF/ TEST/ THRESHOLD

Topics include: Introduction to the Mission, background and accomplishments of the Frank J. Seiler Research Laboratory at the United States Air Force Academy; publications and presentations during FY. 66; current research projects; bibliographies of staff members. Research is being carried out in the following general areas: system optimization, programming and control; fluid dynamics; physical and organic chemistry. TAB

N67-17960# Federal Aviation Agency, Atlantic City, N. J. Test and Evaluation Div.
TESTING OF REFLECTIVE MARKERS FOR INDICATING THE THRESHOLD AND CENTERLINE OF RUNWAYS FOR SMALL AIRPORTS Interim Report
N. H. Twichell and Cecil B. Phillips Dec. 1966 28 p
(FAA-RD-66-71)

Technical tests were performed to investigate the usefulness of retroreflective markers in improving runway threshold and centerline identification at small airports. During the hours of darkness, retroreflective markers were more effective in indicating the centerline than was the painted centerline. Retroreflective markers were less effective in indicating the threshold than were the threshold lights. These markers are not be considered as a replacement for either the centerline or threshold lights. The effectiveness of the markers is a function of the intensity, location and aiming of the aircraft landing lights in relation to the line of sight of the pilot. The markers are inexpensive, easy to install and to maintain. Author

N67-18032* United Technology Center, Sunnyvale, Calif. Research and Advanced Technology Dept.
MODELING AND GROWTH OF RELIABILITY-EXTENDED MODEL Interim Technical Report
W. J. Corcoran 15 Nov. 1966 72 p ref
(Contract NAS7-356)
(NASA-CR-81092; UTC-2140-ITR) CFSTI: HC$3.00 CSCL 14D

In extending the Monte Carlo type computer simulation model, a different approach to the reliability change after a failure or successful test was incorporated to (1) allow for some fraction of noncorrectable failures; and (2) introduce two options. One permits simulation of the effects of testing under various degrees of extreme and relaxed environments; the other (through a block change system) allows for delays in making changes. The basic model, programmed in Algol for the Burroughs 5500 computer, is described. Simulation variables and related input parameters are listed, and a typical form for transmitting input information to the computer operator for a simulation run is included. Examples are given to illustrate the effects of various input parameters and simulation options. Three predictive reliability growth models are

and results of a typical flight test are discussed to show the manner in which the facility is utilized. Some of the operational characteristics of the servocontrolled systems which produce the simulated lunar gravitational field are illustrated. Over 150 flight-test operations have been performed to date with 9 research pilots and astronauts, who have all reported the sensations of actual free flight during the test operations. Approximately 2 minutes of sustained flight are possible by use of the hydrogen peroxide main rockets in the vehicle. This time capability exceeds the time required for the Apollo lunar module to accomplish its terminal maneuver or to touch down on the lunar surface from about 150 feet (45.7 meters). Continuous monitoring of the servo-systems has indicated satisfactory simulation of the lunar gravity, and pilots of the vehicle report negligible effects of the visual cues afforded by the facility structure. Author

12 FLUID MECHANICS

includes boundary-layer flow; compressible flow; gas dynamics; hydrodynamics; and turbulence. For related information see also: 01 Aerodynamics; and 33 Thermodynamics and Combustion.

N67-16776# Aeronautical Research Council (Gt. Brit.)
SIMPLE THEORETICAL AND EXPERIMENTAL STUDIES OF THE FLOW THROUGH A THREE-SHOCK SYSTEM IN A CORNER
E. Eminton London, HMSO, 1966 25 p refs
(ARC-CP-727; AD-800211) CFSTI: HC$3.00/MF$0.65

In the hope of finding the three-shock system in a given corner appropriate to flow at a given Mach number a very simple theoretical model is considered. It assumes that shocks and streamlines are all straight and concentrates on the flow in the region of the point where the main shock branches into two. A shear layer is allowed to originate there and conditions imposed to match both pressures and flow directions on either side of it. The results of the calculations suggest that a more sophisticated theory is needed and a few experiments are made to substantiate this. Theory and experiment together lead to the conclusion that the shock system in a corner is determined not by the way the flow behaves around the branch point but by its behaviour around the feet of the branches which lie within the boundary layer. Thus, viscous effects dominate the flow field and the external inviscid part of the flow appears to be able to accommodate itself readily by small deviations from the simplified model considered here. Author (TAB)

Laboratory, University of California, Berkeley during the period 15 March 1968 through 31 January 1969. Research project are described under the following headings: Bioelectronics; Electromagnetic radiation and propagation; Electron microscopy; Integrated circuits; Plasmas; Quantum and optical electronics; Solid-state and electron devices; and Systems and computer sciences. Author (TAB)

11 FACILITIES, RESEARCH AND SUPPORT

Includes airports; lunar and planetary bases including associated vehicles; ground support systems; related logistics; simulators; test facilities (e.g., rocket engine

N69-33937# ISSUE 19 PAGE 3557 CATEGORY 11
NA-69-9 RD-69-35 69/08/00 UNCLASSIFIED DOCUMEN
T
Simulation test of the Arcata, California, diamo
nd runway centerline Interim report
(Simulated guidance value comparison of diamond
runway centerline markings with standard stripe ce
nterlines)
A/BROWN, G. S.; B/SULZER, R. L.
FEDERAL AVIATION ADMINISTRATION, ATLANTIC CITY,
N. J. (DEPT. OF TRANSPORTATION.) AVAIL- ISSUI
NG ACTIVITY

/*AIRCRAFT GUIDANCE/*FLIGHT SIMULATION/*LANDING
AIDS/*MARKING/*RUNWAYS/ APPROACH/ COSTS/ TEST FAC
ILITIES/ TOUCHDOWN/ VISIBILITY/ VISUAL CONTROL/ VI
SUAL FLIGHT

PAGE 80 (ITEMS 220- 222 OF 364)

N69-33854# Massachusetts Inst. of Technology, Cambridge. Flight Transportation Lab.
A MULTI-REGRESSION ANALYSIS OF AIRLINE INDIRECT OPERATING COSTS
N. K. Taneja and R. W. Simpson Jun. 1968 119 p refs
(Contract C-136-66)
(PB-183012; R 67-2) Avail: CFSTI CSCL 15E

A multiple regression analysis of domestic and local airline indirect costs was carried out to formulate cost estimating equations for airline indirect costs. The costs were broken down into the classification of the uniform system of accounts Form 41, used by the airlines in reporting to the CAB. Thus regression equations were found for annual system expenses and annual station expenses. A stepwise regression technique is used to select the best combinations of independent variables for the equations. The independent variables were data such as revenue passenger miles, passengers enplaned, revenue aircraft miles, total revenue aircraft departures, etc. Author (USGRDR)

N69-33937# Federal Aviation Administration, Atlantic City, N.J. Dept. of Transportation.
SIMULATION TEST OF THE ARCATA, CALIFORNIA, DIAMOND RUNWAY CENTERLINE Interim Report
Guy S. Brown and Richard L. Sulzer Aug. 1969 26 p ref
(NA-69-9; RD-69-35) Avail: Issuing Activity

The guidance value of the Arcata diamond runway centerline paint markings was tested by comparison with the U.S. standard centerline markings in the Dalto/P-3 visual simulation facility. Twenty experienced pilots participated in the testing. Results generally favored the U.S. standard centerline consisting of a 3 foot wide interrupted stripe with 120 foot painted length and 80 foot gaps, as opposed to the 10 foot maximum width diamonds with 75 foot length and spacing. The only exception was that the diamonds were seen farther away prior to touchdown, a result that is attributed to the one-third larger total painted area. Author

two-dimensional, circular, and rectangular tunnels with boundaries of the completely closed, completely open, slotted, or perforated variety. Interference factors accounting for the direct effects of model and wake blockage on the longitudinal velocity and of model lift on the upwash velocity are enumerated. In addition, consideration is given to the variation of the longitudinal and vertical velocity components along the tunnel axis leading to buoyancy and streamline-curvature corrections. Author (TAB)

N69-34285# Aerospace Research Labs., Wright-Patterson AFB, Ohio.
DESIGN PERFORMANCE AND OPETIONAL CHARACTERISTICS OF THE ARL COMPONENT TEST FACILITY Final Report
Eric G. Friberg and Derek G. Moore Jan. 1969 69 p refs
(AD-687861; ARL 69-0007) Avail: CFSTI CSCL 14/2

The document covers a versatile, small-scale test-rig for the evaluation and study of new technologies for basic wind tunnel components. The report describes the facility and its operation.

N70-16980# ISSUE 6 PAGE 980 ... 2 AA
-FAA-NA-70-9 RD-69-60 00/00/00 UNCLASSIFIED DOCUME
NT Evaluation of taxiway guidance signs Interim re
port (Taxiway guidance signs using retro-reflective p
aint)
A/GATES, R. F.; B/PHILLIPS, C. B.
FEDERAL AVIATION ADMINISTRATION, ATLANTIC CITY,
N. J. (DEPT. OF TRANSPORTATION.) AVAIL.NTIS
/*PAINTS/*REFLECTION/*RUNWAYS/*SYMBOLS/ AIRPORT
S/ COATINGS/ IDENTIFYING

...L AIRCRAFT
...on Feb. 1970 69 p refs
... Short Course on V/STOL.

... CFSTI CSCL 01A
...s induced on the aerodynamics
...hover and transition flight by the
...ely high disk-loading propulsion
... treated. (1) the performance
...ut of ground effect, (2) induced
...ght out of ground effect, (3) the
...n, and (4) the effects induced on
...nd effect. Some of the conflicts
... posed by these different modes
... the present state of the art of
Author

...es, helicopters, gliders, balloons,
...cific types of complete aircraft
...s, STOL, and VTOL); flight tests;
...onic boom); safety and safety
...tability and control. For basic
...hics. For related information see
...1 32 Structural Mechanics.

... Wash.
...AGEMENT OF FUTURE
...T
...ed. Aspects of Radio Commun.
... See N70-16962 06-07)

...nent system described herein
...aid the aircraft to 1) control
...ollow a flexibly programmed
...ation control of the airplane and
...ate the preflight checklist and
...ltimode cathode ray tube display
...nd navigational situations; 5)
...nual modes of flight operations;
...effect cg control, store and
...ures, and perform other similar
...ntralized computing. Manual
... is available. A similar increase
... control system is needed to
...and control capabilities of the
...) airplane in improving traffic
Author

..., Calif.
...F ADVANCED AVIONIC
...MS
... Conner *In* AGARD Aeromed.
...light Safety Dec. 1969 12 p
(See N70-16962 06-07)
Avail: CFSTI

Mission analysis and simulation studies, together with creative avionic systems engineering and human factors engineering, aid in the optimization of the man-machine interface. It is necessary during the design evolution, however, that the design be evaluated frequently by operationally oriented aircrews with real world experience to assure success in the optimization. Author

N70-16980# Federal Aviation Administration, Atlantic City, N.J. Dept. of Transportation.
EVALUATION OF TAXIWAY GUIDANCE SIGNS Interim Report
Robert F. Gates and Cecil B. Phillips Jan. 1970 36 p
(FAA-NA-70-9; RD-69-60) Avail: CFSTI

Taxiway guidance signs, 3 feet high and 4 feet wide of a type similar to those used on highways, were evaluated for airport use by means of simulation and actual field trials. Retro-reflective sheeting of red, yellow, and green colors was evaluated for color coding application in a taxiway guidance system. Legends, 18 inches in height, were prepared from white enamel and silver retro-reflective sheeting on a red background, black paint on a yellow background and white enamel on a green background. Retro-reflective discs also were used on the legends for the red and green signs. The discs provided excellent long-range targets but legibility deteriorated as the signs were viewed at distances of 500 to 600 feet and less due to the increased angle from the aircraft light to the sign and the pilot eye, coupled with the white paint appearing black to the observer at these ranges. Author

N70-16991# RAND Corp., Santa Monica, Calif.
CAAC: THE AIRLINE OF COMMUNIST CHINA
Harriett E. Porch Sep. 1969 20 p refs Presented at 6th Ann. Meeting of the Am. Inst. of Aeron. and Astronaut., Anaheim, Calif., 20 Oct. 1969 Submitted for publication
(AD-693926; P-4184) Avail: CFSTI CSCL 1/2

The status of civil aviation in Communist China is assessed. Present airline operations in China consist of fewer than 300 planes providing scheduled service to 60 cities. A table showing the growth in service is presented, and it is noted that while the growth has been steady, it has not been spectacular. It is further concluded that with only four scheduled international routes, Communist China is unlikely to become a major competitor in world aviation in the near future. D.L.G.

N70-17135# Optics Technology, Inc., Palo Alto, Calif.
FIBER OPTICS HAZARD IDENTIFICATION DEVICE Final Technical Report, 17 Jan. 1966 - 30 Apr. 1969
Brian G. Phillips Oct. 1969 54 p
(Contract AF 33(615)-3532)
(AD-697036; AFAPL-TR-69-78; Rept-11014R) Avail: CFSTI CSCL 1/3

This report describes the work done over a period of three years to develop a fiber optics fire hazard detection system for aircraft installation. The distal end of this system which is located within the engine compartment is capable of withstanding temperatures of 1000F, whereas the rest of the system is capable of withstanding temperatures to 500F. During the course of the program, a number of fabrication techniques were developed and high transmittance glasses were evaluated for transmission and strength. In addition to this work, a fire simulator was developed, and this may be mounted within the engine compartment. Author (TAB)

N70-17176# Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt, Brunswick (West Germany). Inst. fuer Flugmechanik.
PARACHUTE ENGINEERING AND RECOVERY SYSTEMS [FALLSCHIRMTECHNIK UND BERGUNGSSYSTEME]
Hans-Dietrich Melzig, ed. Sep. 1969 406 p refs In GERMAN; ENGLISH summaries Proc. of the DGLR-DFVLR-AGARD Symp., Brunswick, 15 - 19 Sep. 1969
(DLR-MITT-69-11) Avail: CFSTI

CONTENTS:

1. DEFINITIONS H.-D. Melzig p 48 - 53 (See N70-17177 06-02)

2. COMMON TYPES OF AERODYNAMIC DECELERATION EQUIPMENT D. Munscher p 54 - 64 (See N70-17178 06-01)

3. PARACHUTE DESIGN CRITERIA H. D. Melzig p 65 - 73 refs (See N70-17179 06-02)

4. THE DETERMINATION OF PARACHUTE SNATCH FORCE P. Schutt p 74 - 95 refs (See N70-17180 06-01)

5. CALCULATION OF FILLING TIME AND FILLING

N62-16476# ISSUE 17 CATEGORY 16 HSR-RR-61/13
-MK-X/ FAA/BRD-401 62/05/00 UNCLASSIFIED DOC
UMENT
(airport marking and lighting systems - operatio
nal tests and human factors, 1959 to 1961)
A/KASSEBAUM, R. G.; B/LUCE, T. S.
HUMAN SCIENCES RESEARCH, INC., MCLEAN, VA.
HUMAN SCIENCES RESEARCH, INC., ARLINGTON, VA.
AIRPORT MARKING AND LIGHTING SYSTEMS- A SURVEY O
F OPERATIONAL TESTS AND HUMAN FACTORS, 1959-1961.
A. S. VAUGHAN, JR., TERRENCE S. LUCE, AND R. G. KA
SSEBAUM. MAY 1962. 217 P. REFS. /CONTRACT FAA/BRD
-401/ /HSR-RR-61/13-MK-X/
/*AIRPORT LIGHT/*HUMAN FACTOR/ ACUITY/ AIRPORT/
APPROACH/ BEACON/ FACTOR/ HUMAN/ INDICATOR/ LIGHT
/ LIGHTING/ LUMINESCENCE/ MARK/ OPERATIONAL/ PATTE
RN/ PERCEPTION/ RECOGNITION/ RUNWAY/ TEST

APPENDIX F

DOD Contact Reports and References

CONTACT BY: PHONE CALL ( ) TO BSCP (X) FROM BSCP | VISITS ( ) VISIT TO BSCP ( ) VISIT TO ______ | OTHER ( ) ______

DATE OF CONTACT: 5-7-71 GROUP: BSCP-TAG DATE OF REPORT: ______

CONTACT NAMES AND POSITIONS: Harvey Miller (his boss or Emil York) Chairman of Military Technology Laboratory; Chief, Organic Coatings Research Branch, Materials Research Support Division

COMPANY OR AGENCY: US Army Equipment R&D Center

ADDRESS: Ft. Belvoir

PHONE: 664-5889

BSCP PERSONNEL: H.N. Cantor

HOW CONTACT ORIGINATED (please be specific)

Bill Williams recommended contact with Miller, York

SUBJECT:

REPORT: 1. Program is in standstill status: airfield marking paints for FAA, Airforce. They did some work, especially paint formulations, for

2. Have made quarterly reports to FAA: Can ask Mr. Fred Horne (x68472)

3. Navy work not done in conjunction with Army work

4. HRB did lit search for him, $500 - $700 cost to Army

5. Got samples of highway marking paint from 6 state highway offices, 1 or 2 that looked "interesting"

6. Need retroreflectivity at a (1.9) different angle of divergence from highway

7. They use glass beads also.

8. Would be interested in attending a joint meeting re the problem area. Further participation would require higher approval

9. See attached sheet.

(if required, use additional paper)

ACTION TO BE TAKEN:

Call Fred Horne and request reports re Miller's work done 5/10/71 JMC

BY: HN Cantor DATE: ASAP

DISTRIBUTION: (please mark each copy)

( ) Chrono File ( ) Shilling ( ) Cantor ( ) Johnston
( ) File: ______ ( ) Weeks ( ) Wilson (X) ICMA
( ) OTU/NASA

REPORT BY: ______
(Signature)

9. Considerable work on high molecular weight linear polymers (epoxy paints) good skid, abrasive, chemical resistance (made by Dow, Shell). Not catalytically cured, thus avoids eventual brittleness as airing proceeds. Information can be gotten from DOW, Dick Beck within D.C. (296-1915). Shell Chemical also has this type of epoxy. Disadvantages are slower drying, ketone solvents may blister a subcoat paint.

CONTACT BY: PHONE CALL ( ) TO BSCP (X) FROM BSCP | VISITS ( ) VISIT TO BSCP ( ) VISIT TO ______ | OTHER ( ) ______

DATE OF CONTACT: 5/10/71 GROUP: BSCP/TAG DATE OF REPORT: ______

CONTACT NAMES AND POSITIONS: Fred Horne
Airport Pavement R&D

COMPANY OR AGENCY: FAA/DOT-R&D Office
ADDRESS: ______
PHONE: 426-8427

BSCP PERSONNEL: H.N. Cantor

HOW CONTACT ORIGINATED (please be specific)

H. Miller (DOD-Army) recommended contact

SUBJECT: Procure copies of Miller's DOD/FAA Reports

REPORT:

- Skid resistance quality paint (aircraft runway problems); other considerations secondary
- Belvoir (epoxy lacquer, ground glass/aluminum oxide)
- Reports are preliminary
- As responsible for the Atlantic City work get their reports from NTIS (visibility)

(if required, use additional paper)

ACTION TO BE TAKEN:

He will send copies of their (Belvoir) reports Received

BY: Horne DATE: ASAP

DISTRIBUTION: (please mark each copy)

( ) Chrono File ( ) Shilling ( ) Cantor ( ) Johnston
( ) File: ______ ( ) Weeks ( ) Wilson ( ) ICMA
( ) NASA/OTU

REPORT BY: ______
(Signature)

CONTACT BY: PHONE CALL ( ) TO BSCP (X) FROM BSCP | VISITS ( ) VISIT TO BSCP ( ) VISIT TO ________ | OTHER ( ) ________

E OF CONTACT: 5/26/71 GROUP: BSCP-TAG DATE OF REPORT: ________

CONTACT
NAMES AND POSITIONS: Dick Beck with
Government Relations Manager

COMPANY OR AGENCY: DOW Chemical Co.
ADDRESS:
Washington, D.C. PHONE: ________
BSCP PERSONNEL: H.N. Cantor

HOW CONTACT ORIGINATED (please be specific)
Harvey Miller suggested I call regarding information on high molecular weight linear polymers (epoxy paints)

SUBJECT: Request for product information
REPORT:

- Work done at Belvoir for FAA, Air Force by Miller/Belvoir Materials Research Support Division

- DOW did original formation work. FAA tested at Dulles

- Program in development stage: material not yet put into specification form. DOW has done some of its own testing. While more expensive than TTP-85 alkyd striping, but better performance and longer life. It is tough, resilient and well adherent. Drying time is 10 minutes, perhaps less, for 12-15 mils wet.

Recommended we contact Will. J. Helm (USAF) AFPRE Directorate of Civil Engineering
Bolling AFB 0X3-1897

(if required, use additional paper)

ACTION TO BE TAKEN:

BY: ________ DATE: ________

DISTRIBUTION: (please mark each copy)

( ) Chrono File	( ) Shilling	( ) Cantor	( ) Johnston
(X) File: Pavement Striping	( ) Weeks	( ) Wilson	(X) NASA OTU
			(X) ICMA

REPORT BY: ________

CONTACT REPORT

C NTACT BY: PHONE CALL ( ) TO BSCP (X) FROM BSCP | VISITS ( ) VISIT TO BSCP ( ) VISIT TO ______ | OTHER ( ) ______

[DAT]E OF CONTACT: 6/2/71 GROUP: BSCP/TAG DATE OF REPORT: 6/2/71

[C]ONTACT

NAMES AND POSITIONS: William T. Helm

Directorate of Civil Engineering / Code AFPRE

COMPANY OR AGENCY: U.S. Air Force

ADDRESS: Bolling Air Force Base
Washington, D.C. PHONE: OX3-1897

BSCP PERSONNEL: Herbert N. Cantor

HOW CONTACT ORIGINATED (please be specific)

Dick Beckwith (DOW-DC) suggested I contact Mr. Helm

SUBJECT: Extent of A.F. R&D in Pavement Stripping

REPORT:

1. Application of P/S not a problem - current equipment is ok (they need 3 ft wide stripers - they have 17 machines)
2. Have joint contract (FAA/Army) restriping at Belvoir. Some problems. Final test & evaluation at Atlantic City FAA facility.
3. Helm is evaluating acrylic emulsion print (works with Miller at Belvoir)
4. May use 2 types of paint for air fields; acrylic emulsion paint and TTP-85 spec paint being developed by Miller/Belvoir for FAA.
5. Current TTP-85 spec paint is marginal and quality control by GSA is poor. Many technical problems, also.
6. Horne (FAA) the key contact re FAA striping work.
7. Noted the Highway Research Board has committee on pavement striping. Chairman is at Michigan State University.
8. Noted a trend towards use of standard specs rather than test requirements by states.
9. Would be interested attending a joint meeting with ICMA.

(if required, use additional paper)

[A]CTION TO BE TAKEN:

BY: ______ DATE: ______

[D]ISTRIBUTION: (please mark each copy)

( ) Chrono File	( ) Shilling	( ) Cantor	( ) Johnston
( ) File: Pavement Striping	( ) Weeks	( ) Wilson	(X) ICMA/Loren/Havlick
			(X) NASA-OTU

REPORT BY: ______
(Signature)

CONTACT REPORT

CONTACT BY: PHONE CALL ( ) TO BSCP (X) FROM BSCP | VISITS ( ) VISIT TO BSCP ( ) VISIT TO ______ | OTHER ( ) ______

DATE OF CONTACT: 5/26/71 GROUP: BSCP-TAG DATE OF REPORT: ______

CONTACT

NAMES AND POSITIONS: William T. Helm
Directorate of Civil Engineering Code AFPRE

COMPANY OR AGENCY: U.S. Air Force
ADDRESS: Bolling Air Force Base
Washington, D.C. PHONE: OX 3-1897
BSCP PERSONNEL: H.N. Cantor

HOW CONTACT ORIGINATED (please be specific)

Dick Beckwith (DOW-DC) suggested I contact Mr. Helm

SUBJECT: Extent of AF R&D in Pavement Striping

REPORT:

On TDY until 1 June

(if required, use additional paper)

ACTION TO BE TAKEN:

I will call him back.

BY: HNC DATE: 1 June 1971

DISTRIBUTION: (please mark each copy)

( ) Chrono File
(X) File: Pavement Striping
( ) Shilling
( ) Weeks
( ) Cantor
( ) Wilson
( ) Johnston
(X) ICMA Loren/Havlick
(X) NASA-OTU

REPORT BY: ______
(Signature)

CONTACT REPORT

C NTACT BY: PHONE CALL — ( ) TO BSCP; (X) FROM BSCP | VISITS — ( ) VISIT TO BSCP; ( ) VISIT TO ________ | OTHER — ( ) ________

'E OF CONTACT: 5/10/71 GROUP: BSCP-TAG DATE OF REPORT: ________

ONTACT
NAMES AND POSITIONS: R.W. Drisko/or E.S. Matsui, P.J. Hearst, J.B. Crilly

COMPANY OR AGENCY: U.S. Naval Civil Engineering Laboratory
DDRESS: Port Hueneme, California
PHONE: (805) 982-4658

BSCP PERSONNEL: H.N. Cantor

HOW CONTACT ORIGINATED (please be specific)

As a result of citations in STIF search

SUBJECT: Status of their pavement marking research

EPORT:

- Nothing now going on: did some work and was completed. Have dropped out of R&D in this area

- Recommended talking Chaiken

- Airfield striping paint spec. in preparation in D.C.

(if required, use additional paper)

CTION TO BE TAKEN:

He will send copy of his report to me Received

BY: Drisko DATE: ________

DISTRIBUTION: (please mark each copy)

( ) Chrono File	( ) Shilling	( ) Cantor	( ) Johnston
( ) File: ________	( ) Weeks	( ) Wilson	( ) ICMA
			( ) NASA/OTU

REPORT BY:

X70-14555# ISSUE 12 PAGE 842 CATEGORY 11 AD-866657L NCEL-TN-1071 00/00/00 UNCLASSIFIED DOCUMENT GOVT. AGCY. ONLY
Protective properties of coatings as measured by dew-cycle accelerated weathering Interim report, Mar. 1965 - Jun. 1969
(Measurement of protective properties of coatings under conditions of dew cycle and salt water)
A/HEARST, P. J.
NAVAL CIVIL ENGINEERING LAB., PORT HUENEME, CALIF.

/*DEW/*ENVIRONMENTAL TESTS/*PROTECTIVE COATINGS /*SALT BATHS/*WEATHERING/ CORROSION/ HUMIDITY/ SALT SPRAY TESTS/ SURFACE REACTIONS

X68-13389# ISSUE 8 PAGE 701 CATEGORY 18 R-562 AD-826177L 68/01/00 UNCLASSIFIED DOCUMENT GOVT. AGCY. ONLY
Evaluation of six heat reflective paints Final report, Aug. 1964 - Aug. 1967
(Post-two-year evaluation of heat reflective paints)
A/CRILLY, J. B.
NAVAL CIVIL ENGINEERING LAB., PORT HUENEME, CALIF.

/*ENVIRONMENTAL TESTS/*PAINTS/*PLASTIC COATINGS /*PROTECTIVE COATINGS/*THERMAL RESISTANCE/ RADIANT COOLING/ REFLECTANCE/ SURFACE COOLING

X68-11771# ISSUE 4 PAGE 322 CATEGORY 18 N-934 AD-822962L 67/10/00 UNCLASSIFIED DOCUMENT GOVT. AGCY. ONLY
Miscellaneous field experiences with airfield marking paints
(Airfield marking paint performance tests)
A/DRISKO, R. W.
NAVAL CIVIL ENGINEERING LAB., PORT HUENEME, CALIF.

/*MARKERS/*PAINTS/*PERFORMANCE TESTS/*RUNWAYS/ AIRPORTS/ LANDING AIDS/ PLASTICS/ POLYESTERS

X65-18950# ISSUE 20 PAGE 1667 CATEGORY 31
FDFR-TM-64-19 AD-451791 64/06/00 UNCLASSIFIED
DOCUMENT GOVT. + CONTR. ONLY
Investigation and test of self-luminous markers
for aerospace vehicle crew stations
(Tritium activated phosphorescent paint markings
for crew station areas applications - visibility,
handling, and durability characteristics of proto
type markers)
A/GATENBEE, R. J.
AIR FORCE SYSTEMS COMMAND, WRIGHT- PATTERSON AFB
, OHIO. (FLIGHT DYNAMICS LAB.)
JUN. 1964 19 P REFS
/*PAINT/*PHOSPHORESCENCE/*TRITIUM/ AEROSPACE/ A
REA/ CHARACTERISTICS/ CREW/ DURABILITY/ HANDLING/
MARKER/ STATION/ VEHICLE/ VISIBILITY

N65-85379 PLASTEC-1 PB-161947 AD-244104 60/10/
00 UNCLASSIFIED DOCUMENT
State of the art. Flake-glass laminates
PICATINNY ARSENAL, DOVER, N. J. (PLASTICS TECH
NICAL EVALUATION CENTER)
OCT. 1960 129 P REFS
/ BEAD/ BINDER/ COATING/ FABRICATION/ FLAKE/ GL
ASS/ LAMINATE/ MANUFACTURE/ PROPERTY/ RESIN/ RIBBO
N/ ROLLING/ TAPE/ TEST

N66-81159 R-323 AD-167322 64/06/30 UNCLASSIF
IED DOCUMENT
Reflectivity of airfield marking paints
A/DRISKO, R. W.
NAVAL CIVIL ENGINEERING LAB., PORT HUENEME, CALI
F.
30 JUN. 1964 19 P
/ AIRPORT/ INFRARED/ MOVEMENT/ PAINT/ REFLECTIO
N/ RUNWAY/ SAFETY/ SPECTRUM/ SURFACE/ VISIBLE

N68-17779# ISSUE 8 PAGE 1191 CATEGORY 18 R
-556 AD-663562 67/12/00 UNCLASSIFIED DOCUMENT
Airfield marking paints. 4 - Effect of paint fl
exibility on slurry sealed asphalt
(Field tests of airfield marking paint flexibili
ty on slurry sealed asphalt)
A/DRISCO, R. W.
NAVAL CIVIL ENGINEERING LAB., PORT HUENEME, CALI
F. AVAIL.NTIS
/*AIRFIELD SURFACE MOVEMENTS/*LANDING AIDS/*MAR
KINGS/*PAINTS/*VISUAL AIDS/ AIRCRAFT LANDING/ ASPHA
LT/ MECHANICAL PROPERTIES/ RUNWAYS/ SEALING

low density. However, the surface of unprotected glass contains flaws which grow under low stress in moist conditions to critical size for failure. Various methods were used to investigate and increase the reliability of glass under stress. Data were obtained on failure of unprotected glass plates subjected to biaxial tension at about 50 percent relative humidity. Analysis by extreme value statistics indicated that the failure condition could be represented by a plane surface in a three dimensional coordinate system composed of extreme value probability, log stress, and log time. Removal of surface flaws by etching in 5 percent aqueous hydrofluoric acid increased the mean failure strength from approximately 30,000 psi to 145,000 psi, with a value of 300,000 psi biaxial tension being attained in one case. Increases in lifetimes of one, two, and three orders of magnitude were obtained by protecting the glass from atmospheric moisture by preheating and coating with petrolatum, preheating glass and coating with preheated petrolatum, and experimenting at -30F, respectively. Slight improvement in minimum time to failure was obtained by eliminating the weaker specimens by proof testing. Author (TAB)

N68-17779# Naval Civil Engineering Lab., Port Hueneme, Calif.
AIRFIELD MARKING PAINTS. 4: EFFECT OF PAINT FLEXIBILITY ON SLURRY SEALED ASPHALT
Richard W. Drisco Dec. 1967 32 p refs
(R-556; AD-663562) CFSTI: HC $3.00/MF $0.65

A field exposure study was conducted on experimental airfield marking paints with relatively high flexibilities. While flexibility must be greater than the minimum required in Federal Specification TT-P-85b for good paint performance, a further increase in flexibility does not necessarily result in better performance. Short oil length alkyd and oleoresinous paints do not perform well; medium oil length paints performed very well; longer oil length paints generally performed somewhat poorer than medium oil length paints, especially for the alkyd formulations. While incorporation of organic plasticizers into paints generally increased flexibility, it did not usually improve the field performance. A statistical analysis of the test variables revealed the following: Oleoresinous phenolic varnish generally performed better than alkyd paint stripes. Lifting was greater for double-thickness thickness stripes than for single-thickness stripes. Cracking was faster for long oil than medium oil alkyd paints and for medium oil than for long oil oleoresinous paints. Medium oil paints had less cracking overall than long oil paints. There was generally less cracking and lifting with paints containing no plasticizer than those with one. Tricresyl phosphate formulations generally had less edge cracking and lifting than comparable formulations with dibutyl phthalate as a plasticizer. There was a high correlation between edge cracking and the lifting of slurry seal. Author (TAB)

N68-17893# Princeton Univ., N. J. Frick Chemical Lab.
SOLID "LIQUID CRYSTAL" FILMS OF POLY-γ-BENZYL-L-GLUTAMATE
E. T. Samulski and Arthur V. Tobolsky Dec. 1967 8 p refs
(Contract Nonr-1858(07))
(ONR-TR-RLT-103; AD-663705)

Cast solid films containing rigid alpha-helical molecules exhibit a molecular structure similar to that found in the liquid crystalline phase. Optical measurements and anisotropic swelling of the films are interpreted in terms of a preferential orientation of the liquid crystalline structure in the film. Author (TAB)

N68-17910# Air Force Inst. of Tech., Wright-Patterson AFB, Ohio. School of Engineering
EFFECT OF VACUUM ON THE STRENGTH OF BALSA WOOD
F. E. Blair, S. W. Johnson, and P. J. Torvik 1967 30 p refs
(AFIT-TR-67-4; AD-663920)

Previous investigations have shown that exposure to vacuum has little effect on the ability of balsa wood to absorb energy. Because this material has, in addition to its energy absorbing capability, a favorable strength to weight ratio and can be cut and shaped with ease, the use of balsa wood as load carrying members in space is a distinct possibility. In this investigation, specimens of oven dry balsa were loaded to failure in either bending or compression after exposure to vacuums of 0.0001 to 0.00001 torr for periods as long as twelve days. Some specimens exposed to vacuum were tested in vacuum; others were tested in air. As controls, the strength properties of similar specimens which had not been subjected to vacuum were determined. The effect of vacuum on compressive and bending strengths was found to be negligible. A small weight reduction primarily due to a loss of moisture while in vacuum was observed, but no damage to the cellular structure of the wood was detected.*

N66-11269# ISSUE 2 PAGE 242 CATEGORY 15 CR
DLR-3243 AD-615880 65/01/00 UNCLASSIFIED DOCUM
UNT
A METHOD OF SILVER PLATING GLASS BEADS TECHNICAL
REPORT, JUN. - AUG. 1964
(CHEMICAL METHOD FOR PLATING GLASS BEADS WITH UN
IFORM COAT OF SILVER)
A/FOX, L. E.
ARMY CHEMICAL CENTER, EDGEWOOD, MD. (CHEMICAL
RESEARCH AND DEVELOPMENT LABS.)
JAN. 1965 18 P REFS
/*CHEMICAL ANALYSIS/*GLASS COATING/*PLATING/*SI
LVER/ ANALYSIS/ APPARATUS/ BEAD/ CHEMICAL/ COATING
/ COMPOUND/ DIELECTRICS/ DIFFUSION/ GLASS/ MATERIA
L/ METAL/ NITROGEN/ NONCONDUCTOR/ ORGANIC/ REDUCTI
ON/ UNIFORM/ VAPORIZATION

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...ures, and ... operates ...rd model ...njet am- ...ted The ...peratures ...e of 148 ...m^{2}a (50 ...^{2}a (70.4 ...s, design ... program. Author

X N66-11269# Army Chemical Center, Edgewood, Md. Chemical Research and Development Labs.
A METHOD OF SILVER PLATING GLASS BEADS Technical Report, Jun.–Aug. 1964
Lloyd E. Fox Jan. 1965 18 p refs
(CRDLR-3243; AD-615880)

A chemical method is described for plating glass beads with a uniform coat of silver. The object of this work was to develop a technique of plating beads uniformly with a maximum of 6% by weight of silver while maintaining their smooth spherical shape. The method is based on the reduction of silver from an ammoniacal silver nitrate solution. Results using formaldehyde and sodium potassium tartrate as reducing agents are discussed. It is concluded that this chemical method may be used to plate glass beads with a uniform coat of silver. By this procedure, using sodium potassium tartrate, a smooth coat giving up to 7% silver by weight on beads having a mass median diameter of 32 microns can be obtained. Author (TAB)

N66-11314# Nuclear Metals, Inc., Concord, Mass.
TECHNICAL PAPERS OF THE SIXTEENTH METALLOGRAPHIC GROUP MEETING
H. Roth Roman, comp. Washington, AEC, 31 Aug. 1964 127 p refs Meeting held at Hanford Atomic Products Operation, Richland, Wash., 28–29 Mar. 1962
(NMI-4998; CONF-620301) CFSTI: $4.00

CONTENTS:

1. MOUNTING OF METALLOGRAPHIC SAMPLES IN EPOXY RESINS USING MULTIPLE CAVITY MOLDS D. M. Hewette, II and R. S. Crouse (Oak Ridge Natl. Lab.) p 1-5 (See N66-11315 02-15)
2. THE APPLICATION OF WAX LAPS TO VIBRATORY POLISHERS E. N. Hopkins and D. T. Peterson (Iowa State Univ. of Sci. and Tech.) p 6–13 ref (See N66-11316 02-15)
3. THIRTY-FIVE MILLIMETER COLOR PHOTOMICROGRAPHY E. H. Hopkins and D. T. Peterson (Iowa State Univ. of Sci. and Tech.) p 14–19 (See N66-11317 02-14)
4. METALLOGRAPHIC STUDY OF THE ANNEALING BEHAVIOR OF ALUMINUM-SILICON EUTECTIC ALLOY R. H. Todd (Hanford Atomic Products Operation) p 20–41 refs (See N66-11318 02-17)
5. MICROSTRUCTURAL CHANGES DURING THE α-β-α TRANSFORMATION OF URANIUM C. L. Angerman (Du Pont de Nemours (E. I.) and Co.) p 42–47 refs (See N66-11319 02-17)
6. METALLOGRAPHY OF URANIUM AT ELEVATED TEMPERATURES W. N. Wise (Natl. Lead Co. of Ohio) p 48–56 ref (See N66-11320 02-17)
7. IDENTIFICATION OF CARBIDES, NITRIDES, AND OXIDES OF COLUMBIUM BY ANODIC STAINING R. S. Crouse (Oak Ridge Natl. Lab.) p 57–64 refs (See N66-11321 02-17)
8. MATERIALS RESEARCH WITH THE SCANNING MICROPROBE ANALYZER J. W. Lenke and R. F. Domagala (IIT Res. Inst.) p 65–76 refs (See N66-11322 02-15)
9. ELECTRON MICROSCOPY OF SINTERED BERYLLIA R. C. Rau p 77–94 refs (See N66-11323 02-15)
10. ELECTRON MICROSCOPE STUDIES OF IRRADIATED A-286 ALLOYS R. C. Rau (GE) p 95–107 refs (See N66-11324 02-17)
11. POSSIBLE ARTIFACTS ASSOCIATED WITH THE MICROSTRUCTURE OF URANIUM DEVELOPED BY ION BOMBARDMENT T. K. Bierlein, B. Mastel, and R. D. Leggett (Hanford Atomic Products Operation) p 108–123 refs (See N66-11325 02-23)

N66-11315 Oak Ridge National Lab., Tenn.
MOUNTING OF METALLOGRAPHIC SAMPLES IN EPOXY RESINS USING MULTIPLE CAVITY MOLDS
D. M. Hewette, II and R. S. Crouse *In* Nucl. Metals Tech. Papers of the 16th Metallog. Group Meeting 31 Aug. 1964 p 1–5 (See N66-11314 02-15) CFSTI: $4.00

Multiple cavity molds have been developed for mounting metallographic samples in epoxy resins. For general laboratory use the molds are fabricated from stainless steel. The use

X

N68-23974# ISSUE 13 PAGE 2049 CATEGORY 11
NCEL-TR-568 AD-667234 68/03/00 UNCLASSIFIED DO
CUMENT
Measurement of airfield marking paint flexibilit
y
(Elongation tests on free paint films to determi
ne runway marking paint flexibility)
A/DRISKO, R. W.; B/MATSUI, E. S.
NAVAL CIVIL ENGINEERING LAB., PORT HUENEME, CALI
F. AVAIL.NTIS

/*ELONGATION/*MARKERS/*PAINTS/*RUNWAYS/*TENSILE
STRENGTH/ ELASTIC PROPERTIES/ LANDING AIDS/ MECHA
NICAL PROPERTIES/ PERFORMANCE TESTS/ THIN FILMS

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at discrete times to define the aerodynamic forces acting on the vehicle as it traversed the blast environment. The report also describes the load transducer used to measure the lateral forces acting on the front slipper of the outrigger rocket sled. The time history of these measured forces and lateral acceleration data are discussed. A maximum force on the front slipper of 76,000 pounds was recorded on one of the runs. Also included is information on the vehicle structural vibration frequencies, which was obtained from reduction of test data in the form of power spectral density. Author (TAB)

N68-23971# Gt. Brit. National Inst. for Research in Nuclear Science, Chilton. Rutherford High Energy Lab.

MODIFICATIONS TO THE RHEL GEOMETRICAL RECONSTRUCTION PROGRAM

J. W. Burren and E. C. Sedman Sep. 1967 38 p
(RHEL/R-150) CFSTI: HC $3.00/MF $0.65

Improvements made to the R.H.E.L. geometrical reconstruction program for bubble chamber tracks are described. Author (NSA)

X**N68-23974#** Naval Civil Engineering Lab., Port Hueneme, Calif.

MEASUREMENT OF AIRFIELD MARKING PAINT FLEXIBILITY

Eddy S. Matsui and Richard W. Drisko Mar. 1968 21 p refs
(NCEL-TR-568, AD-667234) CFSTI: HC $3.00/MF $0.65

A method for determining the elongation of free paint films is discussed. The method is more precise than the ASTM and Federal Test Standard methods which use the mandrel test and it provides a more clear-cut differentiation between different coating films. A statistical analysis was performed on 10 experimental airfield marking paints using data from the free-film percent-elongation tests and from performance tests of the same coatings exposed in the field. The results indicate that there is a definite correlation between the percent elongation (flexibility) and the field performance of airfield marking paints. Author (TAB)

N68-24042# School of Aerospace Medicine, Brooks AFB, Tex. Aerospace Medical Div.

APPARATUS FOR CONTINUOUS SOLIDS-LIQUID SEPARATION, JANUARY-MAY 1967

Michael J. Ryan Feb. 1968 11 p refs
(SAM-TR-68-10, AD-667795)

An apparatus has been developed which allows high filtration with a Millipore filter on a continuous basis. The apparatus consists of a Plexiglas box built around a Millipore filter holder. The entrance port in the box contains a nozzle which increases the velocity of the incoming solution and directs it into a tangential flow pattern, thus simultaneously supplying the mixture to be filtered as well as washing the filter clean of separated solids. Filtrate

V/STOL aircraft simulator trainers, and provides a guide to be used by the government in the preparation of a functional test specification for helicopter and V/STOL aircraft simulator trainers. Author (TAB)

N68-24163*# National Aeronautics and Space Administration, Washington, D. C.

MANNED SPACECRAFT CENTER, HOUSTON, TEXAS

1968 4 p
(NASA Facts 0-9/10-67) GPO: HC $0.15; CFSTI: MF $0.65
CSCL 22D

The Manned Spacecraft Center at Houston, Texas serves as a focal point for the manned space flight program. Its prime responsibilities are: (1) developing the technology required for manned spacecraft in present and future programs; (2) industry management during design, development, and fabrication of spacecraft for on-going programs; (3) selection and training of astronauts; (4) control over NASA manned space flights from time of launch until the accomplished landing; and (5) management of the medical, scientific, and engineering experiments conducted during manned space flights. G.G.

N68-24164*# National Aeronautics and Space Administration, Washington, D. C.

MARSHALL SPACE FLIGHT CENTER, HUNTSVILLE, ALABAMA

1968 4 p
(NASA Facts 0-10/12-67) GPO: HC $0.15; CFSTI: MF $0.65
CSCL 22D

Briefly described are research and development operations at the Marshall Space Flight Center at Huntsville, Alabama. The prime responsibilities of this center at the development of large launch vehicles and spacecrafts for deep space and near earth missions as well as studies of future space exploration projects. G.G.

N68-24177# European Space Technology Center, Noordwijk (Netherlands).

SOLAR CELL PANEL TEST FACILITY ESRO-1 PANEL MEASUREMENT

A. W. Preukschat and G. Seibert Paris ESRO Sep. 1967 30 p refs
(ESRO-TN-9(ESTEC)) CFSTI: HC $3.00/MF $0.65

This paper describes the ESTEC test facility for testing solar cell modules and arrays. The facility consists essentially of a bank of tungsten iodine lamps, an infrared absorbing water filter, and a movable temperature controlled test mounting. The spectral distribution of the light is given and related to absolute intensity. Performance measurements on an ESRO 1 solar cell panel are

APPENDIX G

3M Specifications for Contract and Guaranteed Striping Services

SPECIFICATIONS FOR FURNISHING AND INSTALLATION OF WHITE AND YELLOW INSTANT DRYING PAVEMENT MARKINGS.

1. SCOPE

This specification covers the furnishing and installation of a White and Yellow liquid striping compound of the instant drying type, complete with pre-mixed glass spheres for reflectorization, that is applied to the road surface by a spraying process with surface application of glass spheres which produces an adherent reflectorized stripe of specified thickness and width. The scope of work shall be as designated by the Engineer and as shown on the plans.

2. GENERAL REQUIREMENTS - INSTANT DRYING STRIPING COMPOUND

a. The instant drying striping compound (referred to as compound) shall be a mixture of resins, glass spheres and other materials specifically compounded for traffic markings and which, when properly heated and sprayed on the road surface shall result in a highly reflective line of maximum durability.

b. The composition of the liquid striping compound shall be left entirely to the manufacturer, and it is his responsibility to formulate and produce a liquid striping compound meeting the requirements specified herein.

c. The liquid striping compound complete with pre-mixed glass beads shall be of a uniform consistency, and shall be capable of easy, uniform application by the airless spray type of line marking machine when applied at spray temperatures of 250°F. to 275°F. The liquid striping compound shall be furnished ready for use without thinning or mixing prior to use. The compound shall not exhibit any settling and shall be usable at road surface temperature of 50°F. and air temperature of 50°F. or higher. If application is to be made when temperature of the road surface and air are between 35°F. and 50°F. such as that experienced in early spring and late fall, alternate specification compounds for cold weather use is specified (see attached). The compound shall be usable on clean, dry asphaltic concrete or Portland cement surfaces which are free of residual curing compounds, salt, sand, or traces of moisture.

d. The liquid striping compound shall be packaged in clean, 55 gallon drums, clearly identified as to manufacturer, color, content and quantity and shall be free of any foreign matter.

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Account File No.: ______________________

The compound shall be capable of being stored at temperatures up to 90°F. and out of direct sunlight for periods up to six months from date of delivery and still be suitable for use.

3. SPECIFIC REQUIREMENTS - INSTANT DRYING STRIPING COMPOUND

a. Color: For the White striping compound, the luminous directional reflectivity shall be not less than 72 percent relative to magnesium oxide when tested as specified in ASTM-E 97-55. For Yellow striping compound, the color shall match the standard shade within the green and red tolerance limits when compared with Highway Yellow Color Tolerance Chart obtainable from the United States Bureau of Public Roads, Washington, D.C.

b. Drying Properties: The compound, applied according to the manufacturer's recommendations, including airless spray application, a wet film thickness of 0.015 inches, a material temperature of 250°F. - 275°F. and having a minimum of 3 pounds per gallon of glass beads sprayed on the surface and tested as specified in ASTM D 711-67, shall be dry to no pickup in less than 10 seconds, when the ambient pavement temperature is between 50°F. and 90°F., and in less than 20 seconds when the ambient pavement temperature is between 90°F. and 140°F.

c. Viscosity: The minimum viscosity of the compound shall be 25,000 Centipoise, measured on a Brookfield Viscometer, Model LVT, at 70°F., 6 RPM and a Number 4 spindle after one minute.

d. Percent Solids: The percent of non-volatile solids of the compound by weight shall be 81.5% ± 2% for white and 82.5% ± 2% for yellow. This determination shall be made in accordance with Method 4041, Federal Test Method Standard 141, Paint, Varnish, Lacquer and Related Materials, Methods of Inspection, Sampling and Testing.

e. Weight Per Gallon: The weight per gallon on the compound shall be 12.4 ± .3 lbs./gal. for White and 12.6 ± .3 lbs./gal. for yellow.
Test according to Method 4184. Federal Test Method Standard 141.

f. Pre-mixed Glass Beads: The finished compound shall contain not less than 3.4 nor more than 3.8 pounds of glass beads per gallon.

g. Solvents: The compound shall contain no chlorinated solvents.

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Account File No: ________________

4. GENERAL REQUIREMENTS - GLASS BEADS

Glass beads for use on traffic line paint shall be clear, colorless, and clean, and of such character as to permit their embedment in a pigmented binder having their upper surface exposed to permit the refracting of light rays. The beads shall be bisymmetric bonding in that when applied to a traffic line paint they shall hemispherically embed (to approximately their equator) in the paint film for maximum durability and brightness.

5. SPECIFIC REQUIREMENTS - GLASS BEADS

Hemispherically embedding glass spheres shall conform to the following:

a. Refractive Index:

The spheres shall have an average index of refraction not less than 1.50 nor more than 1.60 when tested by the liquid immersion method at 25°C.

b. Size:

The glass spheres shall conform to the following graduation:

U.S. STANDARD SIEVE NUMBER	PERCENT PASSING BY WEIGHT
U.S. 40	90 - 100%
U.S. 80	0 - 10%

c. Percent Spheres:

A minimum of 75% (by weight) of the spheres shall be true spheres when tested in accordance with ASTM-D-1155-53.

d. Flotation:

A minimum of 90% of the glass spheres shall float on xylol (aromatic solvent) and a minimum of 75% of the glass spheres shall float on heptane (aliphatic solvent) when tested as follows:

A single layer of spheres shall be spread on a clean, inverted pint tin can lid. Solvent shall be slowly introduced with a syringe or dropper at the edge of the lid until it overflows. The percentage of spheres floating on the solvent surface shall be estimated visually.

e. Color:

The glass spheres shall be colorless to the extent that they impart no objectionable day or nighttime hue to the binder when applied at concentrations equal to those used on road surfaces.

6. APPLICATION REQUIREMENTS:

a. All markings of lane lines, centerlines, barrier lines and edgelines of thermoplastic materials shall be applied by an airless spraying process using a self-propelled, truck-mounted vehicle of sufficient size and stability to insure smooth, straight application. The spray equipment operators shall be located on the application vehicle in a location that will enable full visibility of the spray carriage.

b. The truck-mounted application equipment must have the capability of automatically placing new intermittent line patterns as well as continuous lines. The application equipment must also be capable of applying a minimum of 2 lines of one color simultaneously. Markings applied shall be in accordance with the June, 1971 Edition of the Manual on Uniform Traffic Control Services for Streets and Highways.

c. A minimum average wet film thickness of .015" shall be maintained on all markings. This is to be computed on the basis of the amount of material used each day. The glass sphere top coating must be applied by means of pressure-type spray guns designed specifically for this purpose and which will embed the spheres into the line surface to at least one-half their diameter.

d. The work on this project shall be done only on clean, dry pavements, and at road surface temperatures above 35°F.

e. Traffic Control and Safety: Traffic control will be provided by the contractor and conform to the requirements and procedures supplied by ______________________________.
It shall be the responsibility of the contractor to supply all of the necessary auxiliary vehicles (with the exception of any police units) required for this operation.

f. Layout: ______________________________ will supply any necessary road surface cleaning and premarking required for the job, when previously applied lines cannot be followed, or where a center joint is not present, or where new lines are to be placed and no means of guiding are present.

Should the original markings be too faint for retracing, contractor will be given control points at 50-feet intervals along the work area. No passing zone control shall also be

Account Name: ______________________

Account File No: ____________________

provided by ______________________________ if the original markings are too faint for retracing.

g. ______________________________ agrees that it shall provide storage space in its facilities for the marking unit, auxiliary equipment and material throughout execution of the contract.

7. BASIS OF PAYMENT:

The work will be paid for at the contract unit price for each lineal foot of reflectorized pavement markings applied based on the measurements as determined by the ______________________________. The contract prices shall include all material, labor, and equipment required or incidental to the satisfactory completion of the work.

Account Name: ______________________

Account File No: ______________________

SPECIFICATIONS FOR

WHITE AND YELLOW LIQUID STRIPING COMPOUND

Designed for cold weather use (35°F. to 50°F. air and road surface temperature)

1. SCOPE

These specifications cover white and yellow liquid striping compounds, of the instant dry type, complete with pre-mixed glass beads for reflectorization, specifically designed for use in cold weather conditions (35°F. to 50°F.) prevalent in the spring and fall in much of the United States.

2. GENERAL REQUIREMENTS

a. It is the intent of these specifications to procure for use by ______________________________ the most efficient liquid striping compound possible, per unit cost with regard to application and service, which includes speed of application, drying time, daytime appearance, night visibility and durability. The composition of the liquid striping compound shall be left entirely to the manufacturer, and it is his responsibility to formulate and produce a liquid striping compound meeting the requirements specified herein.

b. The liquid striping compound complete with pre-mixed glass beads shall be of a uniform consistency, and shall be capable of easy, uniform application by the airless spray type of line marking machine when applied at spray temperatures of 250°F. to 275°F. The liquid striping compound shall be furnished ready for use without thinning or mixing prior to use. The compound shall not exhibit any settling and shall be usable at road surface temperature of 35°F. to 80°F. and air temperature of 35°F. to 80°F. The compound shall be usable on clean, dry asphaltic concrete or Portland cement surfaces which are free of residual curing compounds, salt, sand, or traces of moisture.

c. The liquid striping compound shall be packaged in clean, 55-gallon drums, clearly identified as to manufacturer, color, content and quantity and shall be free of any foreign matter. The compound shall be capable of being stored at temperatures up to 90°F. and out of direct sunlight for periods up to six months from date of delivery and still be suitable for use.

3. SPECIFIC REQUIREMENTS

a. Color For the white striping compound, the luminous directional reflectivity shall be not less than 72 percent relative to magnesium oxide when tested as specified in ASTM-E 97-55. For yellow striping compound, the color shall match the standard shade within the green and red tolerance limits when compared with Highway Yellow Color Tolerance Chart obtainable from the United States Bureau of Public Roads, Washington, D.C.

Account Name: ____________________
Account File No: ____________________

b. Drying Properties: The compound, applied according to the manufacturer's recommendations, including airless spray application, a wet film thickness of 0.015 inches, a material temperature of 250°F. - 275°F. and having a minimum of 3 pounds per gallon of glass beads sprayed on the surface and tested as specified in ASTM D 711-67, shall be dry to no pickup in less than 10 seconds, when the ambient pavement temperature is between 35°F. and 80°F.

c. Viscosity: The minimum viscosity of the compound at 70°F. shall be 25,000 Centipoise and the maximum viscosity at 35°F. shall not exceed 70,000 Centipoise when measured on a Brookfield Viscometer, Model LVT, at 70°F., 6 RPM and a Number 4 spindle after one minute.

d. Percent Solids: The percent of non-volatile solids of the compound by weight shall be 81.5% ± 2% for white and 82.5% ± 2% for yellow. This determination shall be made in accordance with Method 4041, Federal Test Method Standard 141, Paint, Varnish, Lacquer and Related Materials, Methods of Inspection, Sampling and Testing.

e. Weight Per Gallon The weight per gallon on the compound shall be 12.5 ± .3 lbs/gal. for white and 12.7 ± .3 lbs/gal. for yellow. Test according to Method 4184. Federal Test Method Standard 141.

f. Pre-mixed Glass Beads: The finished compound shall contain not less than 3.5 nor more than 3.9 pounds of glass beads per gallon.

g. Solvents: The compound shall contain no chlorinated solvents.

Account Name: ______________________

Account File No: ____________________

Addendum to Special Report

Review of Federal Research and Development in Pavement Striping Materials

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